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Anatomy, Histological Features, Innervation and Vascularity of the Glenoid Labrum

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Anatomy, Histological Features, Innervation and Vascularity of the Glenoid Labrum

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Glossary

AA: Axillary artery.
ACHA: Anterior circumflex humeral artery.
ACHVs: Anterior circumflex humeral artery and veins.
AG: Ascending glenoid artery.
AV: Axillary vein.
BA: Brachial artery.
BV: Blood vessels.
CGPR: Calcitonin gene-related peptide.
CSA: Circumflex scapular artery.
GL: Glenoid labrum.
HH: Humeral head.
IGHL-A: Inferior glenohumeral ligament anterior band.
IGHL-P: Inferior glenohumeral ligament posterior band.
MGHL: Middle glenohumeral ligament.
NF: Nerve fibres.
PB: Profunda brachii artery.
PCHA: Posterior circumflex humeral artery.
PGP 9.5: Protein gene protein 9.5.
LCVB: Lateral concomitant vein of the brachial artery.
LHBT: Long head of biceps tendon.
LHT: Long head of triceps.
SGHL: Superior glenohumeral ligament.
SHBT: Short head of biceps tendon.
SLAP: Superior labrum anterior to posterior.
SUBS: Subscapular artery.
TM: Teres minor.
Buford complex: Is absence of anterosuperior aspect of the glenoid labrum and cord-like middle glenohumeral ligament.
TUBS: Traumatic instability, with Unilateral involvement, commonly involving a Bankart lesion and often needing Surgery.
AMBRI: Atraumatic instability, which might be Multidirectional, commonly Bilateral and treated by either Rehabilitation or an Inferior capsular shift.
AIOS: Acquired Instability from Overstress and usually needs Surgery.
Hill-Sacks lesion: Posterolateral humeral head fracture as a result of recurrent dislocations.
Baker lesion: Tear in the capsule associated with glenoid labrum lesion and occasionally heamarthrosis.
Melorheostosis: known as lebri disease which is mesenchymal dysplasia manifested by sclerosing bone with dripping appearance.

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Declaration of Authorship

I, Abduelemenem Alashkham declare that this thesis titled "Anatomy, Histological Features, Innervation and Vascularity of the Glenoid Labrum" and the work presented in it is my own.

I confirm that:

- I am the author of the thesis
- Unless otherwise stated, all the references cited have been consulted by me.
- The work has not been previously accepted for a higher degree

Signed:

عبدالمنعم حسن الاشخم

Date: 14.10.2015

Statement by supervisors

I, Roger Soames, have read this thesis titled as "Anatomy, Histological Features, Innervation and Vascularity of the Glenoid Labrum" and certify that the conditions of the relevant ordinance and regulations have fulfilled.

Signed

Date 11th July 2015

Roger Soames, First supervisor

Abstract

Background: The glenohumeral joint is the articulation between the head of the humerus and the glenoid fossa of the scapula, the latter being deepened and extended by the triangular fibrocartilaginous glenoid labrum attached peripherally to the margin of the glenoid fossa. The glenoid labrum plays an important role in glenohumeral joint stability, as well as in helping to protect the articular cartilage. Yet despite this, there is little known regarding its anatomical details, while in the clinical literature few studies have clearly demonstrated its blood and nerve supply.

Aims: The aims of this study are: (I) identify the detailed blood supply of the glenoid labrum macroscopically and histologically; (II) evaluate the mode of the attachment of the glenoid labrum to the glenoid fossa macroscopically and histologically and describe its anatomical variation, including sublabral foramen and Buford complex; (III) assess the shape and dimensions of the glenoid fossa; (IV) assess the shape, thickness and depth of the glenoid labrum; (V) investigate the mode of attachment of the long head of biceps brachii and triceps to the glenoid labrum; (VI) identify the attachment of the fibrous capsule to the glenoid labrum; (VII) evaluate the attachment of the glenohumeral ligament to the glenoid labrum; and (VIII) evaluate the nerve fibres associated with the glenoid labrum.

Materials and methods: 140 formaldehyde embalmed shoulders from 30 males and 40 females were dissected. The first part of the study included macro and microdissection of (i) all muscles surrounding the glenohumeral joint, (ii) the axillary artery and its branches from their origins throughout their distribution, (iii) the glenohumeral ligaments and fibrous capsule. The second part included measurements

taken to (i) the site of origin and thickness of the superior, middle and the anterior and posterior bands of the inferior glenohumeral ligaments, (ii) the type of attachment of the long head of biceps, (iii) the glenoid labrum appearance, consistency and attachment, (iv) the glenoid labrum depth and thickness at the superior (12 o'clock), anterior (3 o'clock), inferior (6 o'clock) and posterior (9 o'clock) regions, (v) the sublabral foramen, (vi) the sublabral recess, (vii) Buford complex, (viii) shape of the glenoid fossa, (ix) the length, width and length at the greatest width of the glenoid fossa with the glenoid labrum attached, (x) the type of the glenoid notch, (xi) attachment of the long head of triceps, and (xii) attachment of the fibrous capsule. The third part was histological investigation of the blood vessels associated with the glenoid labrum, using haematoxylin and eosin stain, and nerve fibres using silver nitrate and immunohistochemistry.

Results: The blood supply of the glenoid labrum by regions is as follows: the superior and anterosuperior regions from the ascending glenoid and suprascapular arteries as well as muscular branches from subscapularis and supraspinatus; the anteroinferior and inferior regions from periosteal branches of the circumflex scapular and inferior glenoid arteries, with the latter being a branch from either the posterior circumflex humeral, circumflex scapular or subscapular artery, as well as muscular branches from triceps and subscapularis; the posteroinferior and posterosuperior regions from periosteal branches from the suprascapular artery, muscular branches from teres minor and infraspinatus and occasionally an ascending branch from the circumflex scapular artery giving periosteal and direct branches to these regions as well as branches from the anterior and posterior circumflex humeral arteries which pierce the capsule anterosuperiorly, anteroinferiorly, inferiorly and posteroinferiorly supplying the anatomical neck, some of which also supply the labrum via the fibrous capsule. In addition, as the glenoid labrum is anchored to the underlying bone it receives a blood supply from the underlying bone and periosteum.

Histologically, the glenoid labrum is fibrocartilaginous becoming more fibrous in its periphery. The whole of the glenoid labrum is vascular with the anterosuperior aspect having a rich blood supply. By using a silver nitrate stain and immunohistochemistry there are free sensory nerve fibres in the glenoid labrum. No mechanoreceptors were observed.

A sublabral foramen was found in 28.57% being slightly more so in males and also more common on the right than the left side in both genders. A Buford complex was seen in 1.42% of specimens. With regards to a sublabral recess, type I was the most commonly seen followed by type II. Regarding the attachment of the long head of biceps to the glenoid labrum, types I and II were the most common.

The glenoid fossa was pear-shaped in 70% and oval in 30%. A bare spot was observed in 80.71% of shoulders, being more common in males than females and significantly longer and wider in males.

The superior glenohumeral ligament was observed in all specimens and the middle glenohumeral ligament in 98.57%. The anterior band of the inferior glenohumeral ligament was found in all specimens, while the posterior band was present in 79.28%.

Conclusion: The glenoid labrum is fibrocartilaginous being more fibrous in the periphery. It has rich blood supply from an ascending glenoid, circumflex scapular, anterior and posterior circumflex humeral, suprascapular, muscular as well as periosteal and cortical arteries, which enables its successful re-attachment. Using silver nitrate and immunohistochemistry this study is the first to confirm the existence of sensory nerve fibres within the substance of the glenoid labrum.

Chapter 1: Introduction

Shoulder instability is a common clinical problem for surgeons: the goal is to restore the ultimate functional anatomy of the joint or to reinforce the disordered joint. However, to achieve this a detailed knowledge of the anatomy and normal variations of the shoulder joint is fundamental. The glenoid labrum plays an important role in shoulder joint stability: it also helps in protecting the articular cartilage of the joint. Despite this, few investigators have evaluated its microscopic anatomy and, to the best of my knowledge, contemporary anatomy textbooks and atlases do not demonstrate any detailed anatomy of the glenoid labrum, while in the clinical literature few studies have assessed its macroscopic and microscopic blood and nerve supply. Therefore, the purpose of this study was to define the vascularity, innervation, and mode of attachment to bone and organisation of fibres within the glenoid labrum.

This study highlights the anatomy, histology, vascularity and innervation of the glenoid labrum for several reasons, for example understanding the vascularity of the labrum will guide treatment of labral pathology which may have implications for its healing potential. Finding blood vessels throughout the labrum would suggest that labral tears occurring in the vascular zone may be amenable to arthroscopic repair or potentially capable of healing rather than debridement. In addition, knowing the vascular zones of the labrum may help surgeons to predict the prognosis of labral tears. Furthermore, an understanding of labral microstructure can lead to an educated approach to surgical timing and repair. Knowledge of normal variants of the glenoid labrum will prevent misinterpretation of any abnormalities present. Finally, knowing all labral variants that may influence shoulder joint biomechanics and predispose them to other abnormalities is fundamental to a good surgical outcome.

Chapter two reviews the literature review and is divided into eight major sections. Section one considers the type of glenohumeral joint and the glenoid fossa including its general anatomy, shape, surface area, volume, height, width, version, inclination, glenoid notch and bare spot, and the humeral head including a general anatomical description, version and diameter. Section two considers (i) the anatomy of the fibrous capsule including a general description of its shape, proximal and distal attachments, relations and mode of attachment of the rotator cuff muscles, its thickness, function, blood supply and histological composition, (ii) the synovial membrane including its attachment, extensions, reflections, functions and bursal communications, (iii) bursae starting with their definition, type, sites and function, (iv) the rotator interval: general anatomy, types, site, shape, composition, function and its relations to glenohumeral joint stability, (v) the synovial recess: definition and general descriptive anatomy, types and incidence. Section three considers the capsular ligaments including (i) the superior, middle and inferior glenohumeral ligaments describing their general anatomy and shape, site of the proximal and distal attachments, number of bands, thickness, incidence, anatomical variations and functions, (ii) the transverse humeral ligament describing its site, number of bands, proximal and distal attachments, incidence, function and histology, (iii) accessory ligaments include the coracohumeral ligament providing a general descriptive anatomy, proximal and distal attachments, number of bands and their shape, anatomical variations and function, and the coracoacromial ligament describing its shape, bony attachments, relations to the surrounding structures, type according to the band number and its functions. In section four, the anatomy of biceps brachii in general then the long head of biceps including the classification of its origin, variations in the attachment, course, number of bands with their incidence as well as its functions, whereas the second concerns the glenoid labrum starting with its definition and general anatomical and histological descriptions, shape in different regions with their incidence, mode of attachment to the glenoid bone and the circumferential variations including the incidence, structures attached including ligaments, muscles and fibrous capsule, brief embryological description of the glenoid labrum, composition of the glenoid labrum, its function, blood supply as well as its anatomical variations and their correlation to other anatomical variations and pathologies such as discoid glenoid labrum, sublabral foramen, Buford complex and sublabral recess. In section five, the stability of the glenohumeral joint and its contributing factors is considered followed by its instability starting with a definition, classification of instability, pathogenesis, the association of the glenoid labrum variations and pathologies and management of instability, including most current operative techniques; thirdly, dislocation of the glenohumeral joint including definition of dislocation and types. In each type of dislocation either anterior, posterior, inferior, intrathoracic or superior, a definition, causes, signs and symptoms, types or sub-classification (acute or chronic), diagnosis, associated lesions and treatments are considered. Section six considers (i) the axillary artery: firstly by defining its origin, course, termination and branches, then briefly the anastomosis around the scapula after which the section explores the variations of the axillary artery and its branches in each of its parts separately and collectively. After that the suprascapular artery is considered in which a full detailed anatomy of its origin, course and relations, branches, incidence and classification, variations of origin, number, course and branches are presented. A brief explanation of the cephalic and axillary veins and nerve supply of the glenohumeral joint have been added at the end of the section. Section seven considers the histology of the glenoid labrum including its consistency, mode of attachment, size and composition. Section eight introduces glenoid labrum lesions including (i) SLAP lesions, classification, pathogenesis and associated lesions, (ii) Bankart lesion, (iii) posterior labral lesion and (iv) circumferential labral lesion, followed by pathologies of the glenoid labrum. Diagnosis of glenoid labrum lesions by physical examination, MR arthrography, MRI and others diagnostic tools such as double contrast CT scan arthrography, double-contrast arthrography, axillary arthrotomography and sonography, fourthly, management of SLAP and Bankart lesions and their outcomes are considered.

Chapter three presents the methods used during the study and is divided into three parts. The first part covers the macro and microdissection of (1) all muscles surrounding the glenohumeral joint, (2) the axillary artery and its branches from their origins throughout their distribution, (3) the glenohumeral joint ligaments and the fibrous capsule. The second part concerns the measurements taken to (i) the site of origin and thickness of the superior, middle and both the anterior and posterior bands of the inferior glenohumeral ligaments (ii) the type of long head of biceps attachment, (iii) the glenoid labrum appearance, consistency, attachment, (iv) the glenoid labrum depth and thickness at the superior (12 o’clock), anterior (3 o’clock), inferior (6 o’clock) and posterior (9 o’clock) regions, (v) the sublabral foramen, (vi) the sublabral recess, (vii) Buford complex, (viii) shape of the glenoid fossa, (ix) the length, width and length at the greatest width of the glenoid fossa with the glenoid labrum attached, (x) the type of glenoid notch, (xi) attachment of the long head of triceps, and (xii) attachment of the fibrous capsule. Part three presented in Appendix 2.

Chapter four presents the results which are also considered in three parts. The first part considers the ascending glenoid, subscapular, circumflex scapular, inferior glenoid, anterior circumflex humeral, posterior circumflex humeral and suprascapular arteries describing their origin, site, course, length, thickness, branches and variations. It also includes the incidence of the common trunks of origin of the axillary artery stating their origin, site, length, diameter and branches. Finally, this part provides the venous network of the glenohumeral joint and their tributaries. The second part presents (1) measurement of the glenoid labrum including shape, consistency, thickness and depth, (2) the incidence of sublabral foramen, Buford complex, types of the long head of biceps attachment then giving the shape of the glenoid fossa and the type of the glenoid notch with their incidence, (3) description and measurement of the glenohumeral ligaments, (4) measurement of the bare spot, (5) origin of the long head of triceps, (6) measurement of the length, width and length at maximum width, (7) length and thickness of tuberculohumeral ligament (8) types with incidence of the sublabral recess. The third part concerns the histology, blood supply and innervation of the glenoid labrum using haematoxylin and eosin, silver nitrate and immunohistochemistry.

Chapter five is the discussion and is divided into eight sections. Section one discusses the shape of the glenoid fossa, glenoid notch, glenoid surface area, volume, height, width as well as the bare area of the glenoid cavity and Tubercle of Assaki. Section two mainly discusses the fibrous capsule in terms of its attachments, orientation and function as well as the synovial membrane including its extensions, reflections, histological compositions, functions and communications. In section three is a discussion of the coracohumeral, coracoacromial, extra-glenohumeral, glenohumeral and transverse humeral ligaments including their measurements, variations, functions and existence. Section four discusses the anatomy of the glenoid labrum and its anatomical variations in terms of its shape, consistency, size, attachments, sublabral foramen, Buford complex, sublabral recess, blood supply and functions, as well as attached structures including long head of biceps tendon. Section five firstly discusses the relationship of the glenoid labrum to different types of glenohumeral joint instabilities. It also emphasizes (i) the incidence of the glenoid labrum to trauma in all types of glenohumeral joint dislocation, (ii) the function of the glenoid labrum in stability. Section six discusses the axillary and suprascapular arteries and their branches and variations, as well as the axillary veins including their tributaries and variations. Section seven considers the histology of the glenoid labrum and discusses how its vascularity and innervation are important. Section eight highlights the function of the glenoid labrum in stability of the glenohumeral joint based on the surgical outcomes.

Chapter six brings all of the preceding sections together to present the overall conclusion of the study.

The aims and objectives of the study are:

1. To identify the detailed blood supply of the glenoid labrum macroscopically and histologically.
2. To evaluate the mode of the attachment of the glenoid labrum to the glenoid fossa macroscopically and histologically and describe its anatomical variation, including sublabral foramen and Buford complex.
3. To assess the shape and dimensions of the glenoid fossa.
4. To assess the shape, thickness and depth of the glenoid labrum.
5. To investigate the mode of attachment of the long head of biceps brachii and triceps to the glenoid labrum.
6. To identify the attachment of the fibrous capsule to the glenoid labrum.
7. To evaluate the attachment of the glenohumeral ligament to the glenoid labrum.
8. To evaluate the nerve fibres of the glenoid labrum.

Clinical relevance:

1. Knowing the vascularity of the glenoid labrum changes the plan of treatment which could lead to better potential healing or arthroscopic repaired rather than trimming.
2. Understanding the microstructure of the glenoid labrum will help in surgical timing and repair.
3. Knowledge of variations of the glenoid labrum could influence shoulder joint biomechanics.
4. Understanding the vascular regions of the glenoid labrum will help provide a better prognosis.
5. Mastering the normal variations of the glenoid labrum will prevent the misinterpretation of abnormalities present.

Chapter 2: literature review

Section 1. Glenohumeral (shoulder) joint

1. Types:

The shoulder joint, also known as the glenohumeral joint (Figure 2.1.1), is defined as a multiaxial synovial joint of the ball and socket variety (Drake et al., 2005). Ellis (2006) states that it is formed by the articulation between the relatively large hemispherical head of the humerus laterally and the relatively small shallow cavity at the superolateral angle of the scapula, the glenoid fossa, situated medially. The glenoid fossa is deepened slightly (Drake et al., 2005) and extended (Smith et al., 1983) by the ring-shaped fibrocartilaginous glenoid labrum (Drake et al., 2005), triangular in cross-section with its peripheral aspect attached to the glenoid fossa margin and its central surface articulating with the humeral head (Smith et al., 1983). According to Sinnatamby (2006) the ratio between the head of the humerus and glenoid cavity is 4 to 1. The presence of the epiphyseal line at the superior part of the glenoid fossa, which extends between the coracoid process anteriorly and scapular posteriorly, permits the joint surfaces to change shape during growth (Palastanga et al., 2006). As the glenohumeral joint is a multiaxial joint, it provides a greater extent of movement compared to the hip joint (Drake et al., 2005). As a consequence of this wide range of motion the glenohumeral joint is relatively unstable (Moore et al., 2010): mobility has been achieved at the expense of stability and security (Palastanga et al., 2006).

2. Articulation of the glenohumeral joint:

The articulation of the glenohumeral joint is between the large rounded humeral head and the small shallow glenoid cavity (Drake et al., 2005) (Figure 2.1.2). The humeral head is larger than the glenoid cavity (Moore et al., 2010), being two-fifths of a sphere with only one-third of the head being in contact with the glenoid fossa at any time during movement at the joint. The humeral head is directed medially, superiorly and slightly posteriorly (Palastanga et al., 2006). As in all synovial joints, both articular surfaces are covered by hyaline cartilage (Moore et al., 2010).

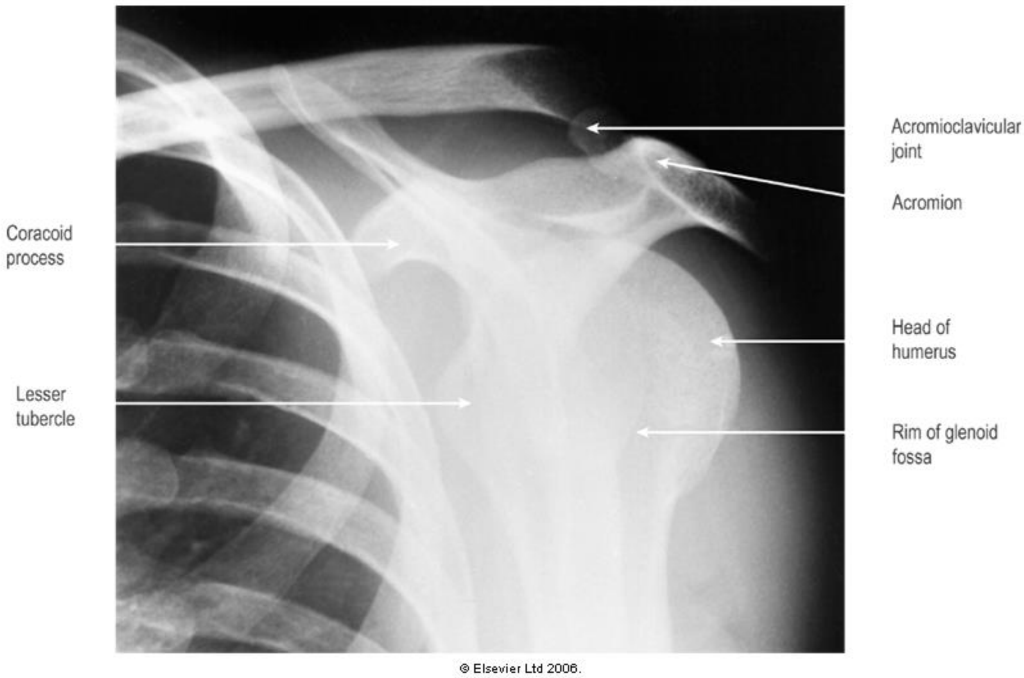


Figure 2.1.1: Radiograph of the left shoulder in the anatomical position, oblique view. Palastanga et al. (2006) Anatomy and Human Movement, 5th edition.

2.1. Glenoid fossa:

2.1.1. General anatomy:

The description of the glenoid fossa is variable: there is no definitive consensus about how to classify the different morphologies of the glenoid fossa. It has been defined as a pear-shaped cavity (Rogers, 1992; Snell, 1995; Palastanga et al., 2006) which faces laterally and to some extent anteriorly (Hall-Craggs, 1990; Sinnatamby, 2006) (Figure 2.1.2). It has also been defined as an oval shallow slightly concave cavity, known as the head of the scapula (Moore et al., 2011), while others have described it as a comma-shaped shallow cavity (Drake et al., 2005). The glenoid fossa is located at the superolateral angle of the scapula facing anterolaterally and slightly superiorly (Palastanga et al., 2006; Moore et al., 2011) where its superior region is confined and the base is irregular, shallow and mildly concave vertically and horizontally (Palastanga et al., 2006). The margins of the glenoid cavity are more ambiguous due to the attachment of the glenoid labrum (Sinnatamby, 2006). It is bounded superiorly by the supraglenoid tubercle (Hall-Craggs, 1990; Rogers, 1992; Drake et al., 2005), which provides attachment for the tendon of the long head of biceps brachii (Drake et al., 2005; Sinnatamby, 2006; Abrahams et al., 2011), and inferiorly by a large triangular infraglenoid tubercle, which gives attachment to the long head of triceps (Hall-Craggs, 1990; Drake et al., 2005; Abrahams et al., 2011). In comparison, the convexity of the humeral head is more than the concavity of the glenoid fossa (Palastanga et al., 2006).

2.1.2. Parameters: shape, surface area, volume, height, width, version and inclination:

Due to the normal anatomical variability of the glenoid fossa many studies have been undertaken to determine its various parameters, including shape, size, height, width, articular surface area, inclination and version in an attempt to find a basic standard classification that can be relied on in surgical intervention.

Glenoid shape:

Most texts describe the shape of the glenoid cavity as being rounded, oval, comma-shaped or pear-shaped (Rogers, 1992; Snell, 1995; Drake et al., 2005; Palastanga et al., 2006; Moore et al., 2011) (Figure 2.1.2). In an assessment of 236 scapulae the underlying reason for the different descriptions of the glenoid fossa shape is related to the presence or absence of a glenoid notch. It was reported that a glenoid notch was present in the anterior margin of the glenoid fossa in 55% (n=129) (47% females, 53% males) of scapulae examined and as a consequence the glenoid fossa appears pear-shaped. A glenoid notch was absent in 45% (n=107) (53% (n=68) males, 47% (n=61) females) and consequently appeared oval in shape. The difference in gender was insignificant. Sixty five percent (n=77) (42% (n=32) males, 58% (n=45) females) of glenoid notches were symmetrical bilaterally (30% (n=36) pear-shaped, 35% (n=41) oval) with no gender differences; for the remaining 35% (66% females, 34% males) the glenoid notches were asymmetrical bilaterally; however the gender difference was significant. The 30% (n=36) symmetrical pear-shaped glenoids is consisted of 31% (n=11) female and 69% (n=25) male scapulae, while the 35% (n=41) symmetrical oval shaped glenoid consisted of 51% (n=21) male and 49% (n=20) female scapulae (Prescher and Klumpen, 1997). In a study of 363 human scapulae to determine gender differences of the glenoid fossa, it was suggested that due to the significant difference in glenoid height and width between males and females, males have a rounded glenoid fossa and females an oval fossa (Merrill et al., 2009). In an earlier study (Checroun et al., 2002) of 412 scapulae (89% (n=367) males, 11% (n=45) females) using 6 glenoid templates it was observed that 71% (n=293) were pear-shaped and 29% (n=119) elliptical. However, some authors state that the transverse diameter of the lower glenoid is greater than that of the upper glenoid, as a consequence the glenoid fossa has become pear-shaped (Iannotti et al., 1992).

Many studies have evaluated the shape of the inferior glenoid suggesting that it is circular; however there is a difference in the percentage of circular and non-circular inferior glenoid fossae in these studies. For example, Aigner et al. (2004) stated that in 50% (n=10) of cases the inferior glenoid was circular, whereas in the other 50% (n=10) it was circular for the inner margin of the glenoid labrum and oval for the glenoid fossa. De Wilde et al. (2004) concluded that the inferior quadrants of the glenoid fossa were circular with an average radius of 14.7 mm (range 12 – 18 mm) to the peripheral articular rim. In a later study by Huysmans et al. (2006) on 40 scapulae with no sign of wear and tear and without referring to gender and race, in 39 scapulae the inferior glenoid was circular with a diameter of 24.7 ± 2.1 mm to the glenoid cartilage rim and 30.5 ± 2.6 mm to the glenoid bone rim. However, in an assessment of 90 patients' shoulders Jeske et al. (2009) reported that the inferior glenoid was circular in all shoulders adding that there was no significant difference in shape between sexes, but with males being on average 3.6 mm larger in diameter than females.

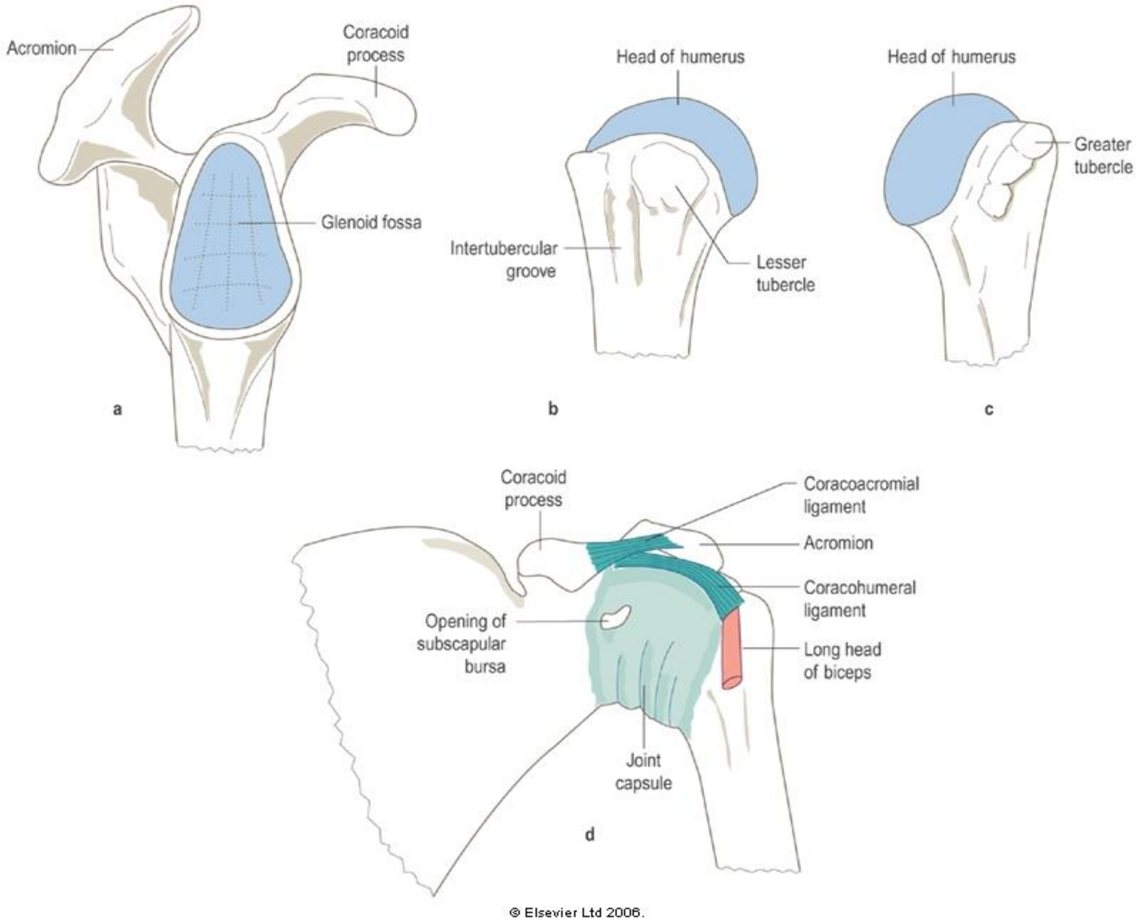


Figure 2.1.2: Articular surfaces of the glenohumeral joint, (a) glenoid fossa, (b) head of the humerus anterior view, (c) head of the humerus posterior view, (d) anterior aspect of the capsule. Palastanga et al. (2006) Anatomy and Human Movement, 5th edition.

Glenoid surface area:

The mean surface area of the inferior glenoid has been reported as 3.2 ± 0.6 cm^2 (Jeske et al., 2009), while the mean diameter of the glenoid cavity in males is greater than in females, being 29.8 ± 2mm and 26.2 ± 2mm respectively. Jeske et al. (2009) also emphasized that there was an appreciable difference in size between the right and left inferior glenoid surface areas of the same individual, 1.8 ± 1.9% between the left and right sides. The surface area of the hyaline cartilage (articular surface) of the glenoid fossa has been reported as 6.03 cm^2 (range 4.47 – 8.6 cm^2) with a mean circumference of 9.12 cm^2 (range 7.8 – 10.8 cm^2) (Aigner et al., 2004). In an evaluation of 32 cadaveric shoulders (Soslowsky et al., 1992) reported that the mean surface area of the glenoid articular surface in males and females was 5.79 ± 1.69 cm^2 and 4.68 ± 0.93 cm^2 respectively. However, using 3D CT scans Kwon et al. (2005) have reported that the mean surface area of the glenoid is 8.7 ± 2.7 cm^2 (range 7.0 – 14.2 cm^2).

Glenoid volume:

In assessments of the volume and morphology of the glenoid vault, 3D CT scans have reported the volume varying from 7.1 to 21.6 cm^3 depending on the size of the scapula. Kwon et al. (2005) added that there was a significant consistent difference between the glenoid surface area and glenoid vault, with a mean difference of 1.4 cm^3. However, in an assessment of glenoid vault morphology its shape was found to be rectangular in coronal section and triangular in transverse section (Bicknell et al., 2007). Furthermore, in a study of 61 scapulae, again using 3D CT scans, Codsi et al. (2008) reported that the shape of the glenoid vault was triangular in all cases: on this basis they suggest 5 sizes of implant that could fit any scapula. In addition, the range of surface areas of the triangular glenoid vault varied between 140.81 – 221.69 mm^2 (Codsi et al., 2008).

Glenoid height:

Glenoid height is described as the interval between the most superior and inferior points on the glenoid fossa. Based on gender, side and method mean glenoid height is variable (Table 2.1.1). Mean glenoid height has been found to be longer in males than females, with the difference being significant in some studies (Mallon et al., 1992; Churchill et al., 2001; Chercoun et al., 2002; Merrill et al., 2009) and not so in others (Ianotti et al., 1992; Bicknell et al., 2007). There is no difference in glenoid height between different races (Churchill et al., 2001; Merrill et al., 2009): Bicknell et al. (2007) also reports no difference in individuals with osteoarthritis. Kwon et al. (2005) assessed 12 scapulae taking measurements directly from the bones and from 3D CT scans: direct measurement was smaller than from 3D CT scans with a confidence limit < 2.12 mm. The authors therefore confirmed that measurement of the glenoid fossa using 3D CT scans was accurate and could be used in preoperative evaluation of the glenoid fossa.

Table 2.1.1: Comparison of different studies on glenoid height (mm); M: males; F: females; No: number.

Study	No	Method	Mean length (range)
Mallon et al. (1992)	28	Scapulae	M: 38 (43 – 45); F: 36.2 (33 – 45)
Iannotti et al. (1992)	140	Patients and scapulae	39 (30 – 48)
Churchill et al. (2001)	172	Scapulae	M:37.5 (30.4 – 42.6); F:32.6 (29.4 – 37)
Checroun et al. (2002)	412	Scapulae	37.9 (31.2 – 50.1)
De Wilde et al. (2004)	98	Scapulae	35.6
Kwon et al. (2005)	12	Scapulae and 3D CT scans	Scapulae: 37.8 (30 – 47) 3D CT scans: 39.1 (31 – 48)
Bicknell et al. (2007)	72	Scapulae	41 ± 6.1
Codsi et al. (2008)	11	Scapulae	35 (33 – 45)
Merrill et al. (2009)	363	Scapulae	M:37.01; F: 33.83

Glenoid width:

Glenoid width is the distance between the most anterior and posterior points on the glenoid fossa. Based on gender, side and method the mean glenoid width has been observed to be variable (Table 2.1.2). Not surprisingly the mean width of the lower half of the glenoid fossa is greater than the upper half with a ratio of 1: 0.80 ± 0.01 (Iannotti et al., 1992). Significant differences in width between genders has been reported by Mallon et al. (1992), Churchill et al. (2001), Chercoun et al. (2002) and Merrill et al. (2009); however no difference has been observed between races (Churchill et al. 2001; Merrill et al., 2009). De Wilde et al. (2004) reported a correlation between glenoid length and width (r = 0.77). Unlike the findings with respect to glenoid height Kwon et al. (2005) report that direct measurement from the bones gave larger widths than did measurements taken from 3D CT scans: nevertheless, they confirm that the accuracy of 3D CT scan is reliable.

Table 2.1.2: Comparison of different studies on glenoid width (mm); M: males; F: females; No: number.

Study	No	Method	Mean length (range)
Mallon et al. (1992)	28	Scapulae	M: 28.3 (24 – 32); F: 23.6 (17 – 27)
Churchill et al. (2001)	172	Scapulae	M: 27.8 (24.3 – 32.5); F: 23.6 (19.7 – 26.3)
Checroun et al. (2002)	412	Scapulae	29.3 (22.6 – 41.5)
De Wilde et al. (2004)	98	Scapulae	25.8
Kwon et al. (2005)	20	Scapulae and 3D CT scans	Scapulae: 26.8 (22 – 35) 3D CT scans: 25.2 (21 – 34)
Bicknell et al. (2007)	72	Scapulae	22.9 ± 4.6
Merrill et al. (2009)	363	Scapulae	M: 28.56; F: 23.67

Glenoid version:

Glenoid version is defined as the orientation of the axis of the glenoid articular surface to the transverse axis of the scapula. Many studies have reported that the version is posterior (retroversion), with the degree of retroversion reported being variable (Table 2.1.3 Walch et al. (1999) classified the morphology of the glenoid into type A (59%, n=49), in which the humeral head was centrally placed with a mean glenoid retroversion of 11.5°; Type B (32%, n=18), in which the humeral head was posteriorly subluxated with a mean glenoid retroversion of 18°; and Type C (9%, n=10), in which the humeral head was centrally placed or posteriorly subluxated with a mean glenoid retroversion of 35°. Couteau et al. (2000) also classified patients into three groups: group A (33.34%, n=4) who had mild rotator cuff tear; group B (50%, n=6) who had primary osteoarthritis; and group C (16.67%, n=2) who had rheumatoid arthritis. They concluded that mean glenoid retroversion for groups A, B and C were 17° (range 12 – 22°), 27° (range 4 – 48°) and 31° (range 25° – 31°) respectively. In a later study Couteau et al. (2001) concluded that version was more specific regarding age and gender, again classifying patients into three groups. Group A (15 patients) had a mild rotator cuff tear; group B (13 patients) had primary osteoarthritis; and group C (4 patients) had rheumatoid arthritis: mean glenoid retroversion for groups A, B and C were 8° (range 2° – 17°), 16° (range 0.2° – 50°) and 15° (range 6° – 22°) respectively. Churchill et al. (2001) used two methods to determine glenoid version, the first used the transverse axis of the scapula and the second placed the scapula in the coronal plane with version being measured perpendicular to the glenoid inclination. Although there was a difference in retroversion between races but there was no difference between males and females of the same race. Nyffeler et al. (2003) have reported a significant difference between version measured from CT scans and conventional radiographs, being 6.5° (range 0° – 21°), leading the authors to conclude that the measurement of glenoid version from standard axillary radiographs, either preoperative or postoperative, is not reliable and that CT scans should be used. Kown et al. (2005) also acknowledge that in measurements from 3D CT scans glenoid version was slightly smaller than direct scapula measurement: however there was no difference between the two sets of measurements. Recently, Rouleau et al. (2010) assessed glenoid version in symptomatic patients using both the Friedman method and the scapular body method. The Friedman method uses a line drawn between the anterior and posterior glenoid margins, with the transverse axis of the scapula evaluated by drawing a line from the mid-glenoid fossa to the medial margin of the scapula: neutral version is when the transverse axis line is perpendicular to the anteroposterior line of the glenoid margin. In the scapula body method the angle of version is the complementary angle between the transverse axis of the scapula and the anteroposterior line of the glenoid margin. In retroversion the posterior margin of the glenoid fossa is medial to the anteroposterior line of the glenoid margin, while in anteversion the anterior margin is medial. The average glenoid version using the scapula body axis was significantly smaller than using the Friedman method. Despite the reliability of both methods Rouleau et al. (2010) suggest that using the Friedman method is easier in individuals with curved scapulae for all glenoid types. Reporting a single value for version assumes that it is the same throughout the glenoid. It has been reported that the superior part of the glenoid fossa is more retroverted than the inferior part as much as 5.5° (Lewis and Armstrong, 2011). In contrast Monk et al. (2001) report that there is more than one angle of version associated with each glenoid. Glenoid version at the equatorial line (mid-glenoid anteroposterior line) could be either retroversion or anteversion with a range of $8{:}3^0$: the mean difference between the superior and inferior aspects of the glenoid fossa was 11.2^0. They conclude that the superior glenoid fossa is retroverted while the inferior is anteverted in relation to the equatorial line.

Table 2.1.3: Comparison of different studies on glenoid retroversion; No: number.

Study	No	Method	Mean retroversion (range)
Mallon et al. (1992)	28	Roentgenogram and CT scan	6° (– 2° ± 13°)
Walch et al. (1999)	113	Friedman method	16° (– 12° to 50°)
Churchill et al. (2001)	172	Transverse axis and coronal plane of the scapula	1.23°
Nyffeler et al. (2003)	25	CT scans	3° (–7° to 16°)
Kown et al. (2005)	12	3D CT scans	1.0° ± 5.4°
Kown et al. (2005)	12	Direct scapula measurement	1.6° ± 5.5°
Rouleau et al. (2010)	116	Scapula body axis	14.84° ± 12.68° (–58.00° to 8.00°)
Rouleau et al. (2010)	116	Friedman method	17.91° ± 12.82° (–56.00° to 12.00°)
Iannotti et al. (2012)	13	3D surgical simulator	13° (1° – 42°)

Glenoid inclination:

Inclination of the glenoid fossa is described as tilting the articular surface of the glenoid fossa about the transverse axis of the scapula. Churchill et al. (2001) report that mean glenoid inclination for males and females was 4° superiorly (range 7° inferiorly, 15.8° superiorly) and 4.5° superiorly (range 1.5° inferiorly to 15.3° superiorly) respectively. They also highlighted that the angle of glenoid inclination varied significantly between race and gender. The mean glenoid inclination of their black and white patients was 3.9° and 4.6° superiorly respectively, while for the white population it was 4.4° and 5.3° superiorly respectively, and for the black population it was 3.6° and 4.2° superiorly respectively. It has been suggested that the superior inclination of the glenoid cavity is a predisposing factor for rotator cuff pathogenesis (Wong et al., 2003), with Konrad et al. (2006) stating that a decrease in the superior inclination of the glenoid cavity results in a significant reduction in superior movement of the humeral head against the glenoid fossa, therefore decreasing the risk of a rotator cuff tear. Using 3D CT scans of the inferior glenoid plane, De Wilde et al. (2010) have observed a difference in inclination between females (mean 22.3^0) and males (mean 20.3^0). However Bishop et al. (2009) report no significant association between increasing glenoid inclination and superior-inferior translation of the glenohumeral joint, therefore they do not concur that superior inclination is correlated with superior humeral translation thereby enhancing subacromial impingement. Bishop et al. (2009) also observed a difference in glenoid inclination between surgical repair of rotator cuff tears and contralateral shoulders.

2.1.3: Glenoid notch:

The presence of a glenoid notch was observed in 55% (n=129) of 236 scapulae by Prescher and Klumpen (1997), who suggest that the tendon of subscapularis, if it passes anterior to the glenoid cavity, could be the cause of atrophic pressure on the bone leading to the formation of a glenoid notch. However, Merrill et al. (2009) reported that a glenoid notch was observed in 80.4% (n=148) of female and 57.6% (n=184) of male scapulae. They have put forward a classification system based on the type of the anterior glenoid notch. In type I the notch is curved, being the most common type in both genders (52.2% (n=96) females, 46.2% (n=85) males); in type II the notch is notched (26% (n=48) females, 10.3% (n=19) males); while in type III the notch is scalloped (2.2% (n=4) females, 1.1% (n=2) males) (Figure 2.1.3). Merrill et al. (2009) also highlight that the location of the glenoid notch is different in females and males: in addition, the average width of the glenoid fossa at the level of the glenoid notch for males and females was 17.57 mm and 19.70 mm respectively.

Figure 2.1.3: Types of glenoid notch (Merrill et al., 2009).

2.1.4: Bare area of the glenoid cavity and Tubercle of Assaki:

There is controversy over the definition of the bare area and Tubercle of Assaki. The bare area is defined as a thinning of the central area of the hyaline cartilage of the glenoid cavity (Kim, 2009). However, it is also described as a focal centrally located cartilaginous defect of the glenoid cavity which is considered a normal variation in adults (Ly et al., 2004, cited in Kim et al., 2010b).

An Assaki tubercle is defined as a thinning of the middle of the articular cartilage and thickening of the subchondral bone (Al–Mulhim, 2013), which is located in the centre of the inferior glenoid cavity (Burkhart et al., 2002, cited in De Wilde et al., 2004). However, according to Warner et al. (1998, cited in De Wilde et al., 2004) the Tubercle of Assaki is defined as the thickest region of subchondral bone of the glenoid fossa due to constraint of the humeral head against the articular surface. Others have reported the Tubercle of Assaki to be the bare area of the glenoid labrum (Paturet, 1951, cited in De Wilde et al., 2004). The bare area of the glenoid was named the 'Tubercle of Assaki' by the French anatomist Lugo et al. (2008). In 2002 the bare area was described as a constant reference point in evaluating of the amount of anterior bone loss from the glenoid rim (Burkhart et al., 2002, cited in Aigner et al., 2004).

The number of specimens showing a bare spot has been observed to be as high as 88% of adults (Resnick et al., 2007 cited in Kim, 2009). In contrast, the incidence of the bare spot, assessed by MRI, in children is very low: children between up to 10 years had no evidence of a bare area, while a small number of those aged 11 to 20 years showed either central or eccentric bare spots in the inferior glenoid cavity (Kim et al., 2010b). A shoulder MRI of a 14 year old boy after a football injury showed a bare spot at the centre of the glenoid (Kim, 2009), while another MRI on a 14 year old with a traumatized shoulder revealed a 4 mm central area of hyaline cartilage loss of the glenoid fossa (diagnosed as glenoid bare spot) without changes in the subchondral bone (Gagliardi and Carino, 2013). No bare spots have been observed in 51 foetal shoulders (Fealy et al., 2000).

In an assessment of the bare spot in glenohumeral joints it was observed to be constant, variable in shape and mostly in an eccentric position within the inferior glenoid cavity (Aigner et al., 2004). The constant appearance was assumed to be the result of the distribution of the hyaline cartilage in the glenoid cavity therefore it cannot be taken as a marker for operative measurement (Aigner et al., 2004). De Wilde et al. (2004) supported these finding in determining the correlation between the bare spot and Tubercle of Assaki. They reported that the Tubercle of Assaki was round to oval in shape with an average diameter of 6mm: in 98.9% (n=97) of specimens the centre of the inferior glenoid was in the anterosuperior quadrant of the surface area of Assaki’s Tubercle. However, Huysmans et al. (2006) found the bare spot in 87.5% (n=35) of scapulae examined, all of which were located in the centre of the inferior glenoid: no significant difference between the measurement from the bare spot to the anterior, inferior, posterior cartilage rim or bony rim was observed. This suggests that the bare spot is the centre of both the articular surface of the inferior glenoid and the bony inferior glenoid except for a small difference to the inferior bony rim.

In an analysis of the distribution of mineralization in the subchondral bone of 28 dominant side throwing shoulders using CT osteoabsorptiometry, the glenoid labrum was divided into one central and 6 peripheral areas: the mechanical stress was found to affect the peripheral regions (anterior, anteroinferior, posterior and posteroinferior) more than the central region (Mochizuki et al., 2005). In an assessment of 44 shoulders by CT osteoabsorptiometry to evaluate the distribution of mineralization of the subchondral bone plate, Schulz et al. (2002) found the maximum density localization showed that long-term stress distribution is in the periphery and is often bicentric.

2.2. Humeral head:

The humeral head constitutes two-fifths of a sphere which faces superiorly, medially and posteriorly (Figure 2.1.2). Regardless of glenohumeral joint position only one third of the humeral head is in contact with the articular surface of the glenoid fossa at any time (Palastanga et al., 2006). A number of studies have shown that humeral head shape, size, diameter, inclination and version are variable (Figure 2.1.4). Retroversion of the humeral head varies remarkably, not only between individuals but also between the right and left sides of the same individual. Depending on factors such methodology, gender and sport type retroversion of the humeral head ranges between -2 and 60^0 (Osbahr et al., 2002; Pearl, 2005; Murachovsky et al., 2007; Thomas et al., 2012; Mastumura et al., 2014; Reagan et al., 2014) (Table 2.1.4). Humeral and glenoid retroversion are significantly greater on the dominant compared to the non-dominant side, being larger in males than females (Mastumura et al., 2014). According to Reagan et al. (2014) there is a significant difference in external and internal rotation between the dominant and non-dominant arms in baseball players, which is also significantly correlated with an increase in retroversion of the humeral head. Osbahr et al. (2002) observed that all the dominant arms of players had greater external rotation, less internal rotation and greater retroversion: the difference being significant between the dominant and non-dominant arms. Moreover, in the dominant arm the correlation between retroversion and external rotation was found to be significant. In a study of handball players Murachovsky et al. (2007) reported a significant difference in retroversion between the dominant and non-dominant arms, being larger on the dominant side. A linear relationship was also noticed between an increase in retroversion and an increase in external rotation. Thomas et al. (2012) reported that the dominant arm shows a significant difference, being more retroverted than the non-dominant arm, but that there is a negative relationship between humeral retroversion and humeral head internal rotation. In a cadaveric study using a surface laser scanner Harrold and Wigderowitz (2012) report that, depending of the level of the plane of the measurement, the angle of retroversion was variable and increased moving superiorly (22.5° ± 11.9°) and decreased moving inferiorly (14.3° ± 9.4°). The mean retroversion of the head of the humerus at the midpoint, which extends between the inferior and superior margin, was 18.6°: consequently the authors suggest that the articular cartilage is not circular. In a study of 60 patients with severe osteoarthritis using 3D CT imaging Sabesan et al. (2014) observed that the relationships between the centre of the humerus and glenoid retroversion with respect to relation to the scapular central line is strong and linear, however no strong correlation was observed in the relation of humeral head alignment to the glenoid plane. The mean humeral scapular alignment was - 2.3%.

The diameter of the articular surface of the humerus is 23.9 ± 1.4mm (Harrold and Wigderowitz, 2012); however, Boileau and Walch (1997) reported a humeral head diameter ranging between 37.1 mm and 56.9 mm (mean 46.2 mm), while the articular surface diameter ranged from 36.5 mm to 51.7 mm (mean 43.3 mm). Mean retroversion of the humeral head through the trans-epicondylar axis was 17.9° and through the tangent elbow axis 21.5°. Milner et al. (2012) reported that the mean humeral head diameter in males was 49 mm and in females 42.1 mm. Inclination of the humeral head articular surface in relation to the humeral shaft ranged from 30° to 55° (Pearl, 2005), while Boileau and Walch (1997) observed it to be between 123.2° and 135.8° (mean 129.6°).

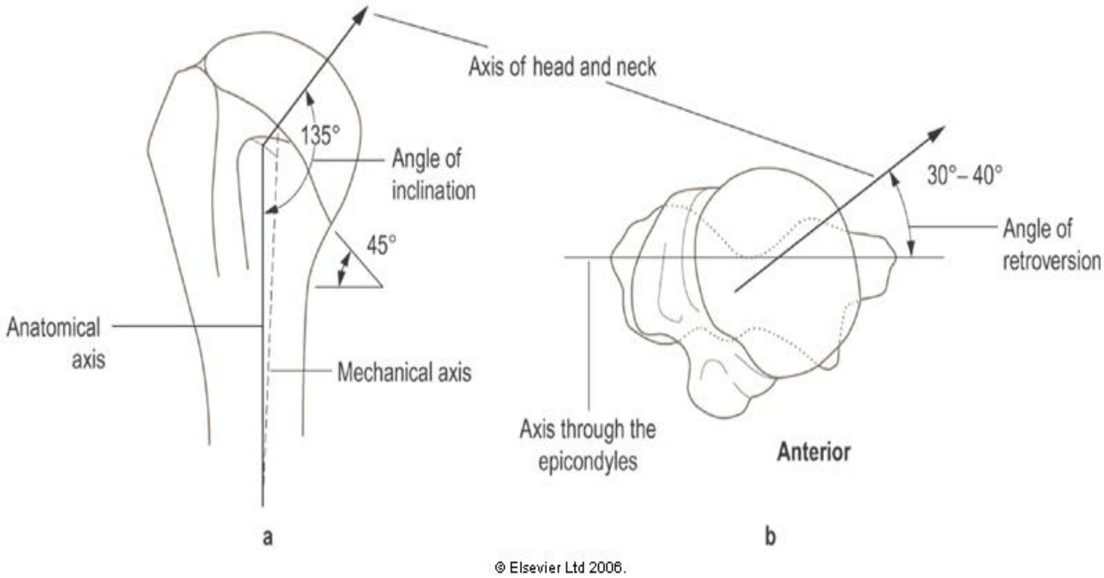


Figure 2.1.4: The angle of (A) inclination and (B) retroversion of the humeral head, Palastanga et al. (2006) Anatomy and Human Movement, 5th edition.

Table 2.1.4: Comparison of different studies on the humeral head version.

Study	Number of cases	Method	Retroversion in Dominant	Retroversion in Non-dominant	Relation
Reagan et al. (2014)	54 baseball players	X-ray	36.6°± 9.8°	26° ± 9.4°	P=0.001
Thomas et al. (2012)	24 baseball players	Ultrasound	- 0.3° ± 12.53°	16.13° ± 11.53°	P=0.0001
Osbahr et al. (2002)	19 baseball players	Soderlund technique	33.2° ± 11.4°	23.1° ± 9.1°	P=0.001
Murachovsky et al. (2007)	17 handball players	X-ray	30.59°	27.53°	P=0.018
Mastumura et al. (2014)	270 non-players	CT scan	28° ± 11°	25 °± 11°	P<0.001

Section 2: Joint capsule, synovial membrane, bursae, rotator interval and synovial recesses of the glenohumeral joint.

1. Joint capsule:

A loose fibrous layer, the joint capsule, surrounds the glenohumeral joint as a cylindrical sleeve where it is attached laterally to the anatomical neck of the humerus on its anterior, superior and inferior aspects (Smith et al., 1983; Drake et al., 2005), as well as to the articular margins of the head, medial to the greater and lesser tubercles of the humerus (Palastanga et al., 2006) (Figures 2.1.2, 2.2.1). The superior aspect of the fibrous capsule is considered to be the strongest and the inferior the weakest (Robinson, 1922). Inferiorly the medial part of the joint capsule extends down the shaft of the humerus by approximately 1 cm (Smith et al., 1983; Palastanga et al., 2006; Sinnatamby, 2006) to enclose the medial end of the upper epiphyseal line of the humerus within the joint capsule; however the greatest part is extracapsular, creating a redundant fold (Robinson, 1922; Palastanga et al., 2006). The presence of this redundant fold allows a wide range of movement, mainly associated with abduction of the upper limb (Williams, 1995; Monkhouse, 2001). With the upper limb in the anatomical position, the redundant fold is lax becoming taut when the arm is abducted. As the capsule extends downward on the shaft inflammation of the upper end of the shaft, inflammation has a potential risk of involving the glenohumeral joint by direct spread (Ellis, 2006).

Medially the joint capsule is attached to the margins of the glenoid labrum and long head of biceps brachii (Palastanga et al., 2006), being attached to the glenoid labrum and scapula just beyond to the supraglenoid tubercle (Sinnatamby, 2006). The fibrous capsule is also attached to the distal margin of the glenoid labrum and adjacent bone where it passes superior to both the supraglenoid and infraglenoid tubercles (Smith et al., 1983). The fibrous capsule is lined by a single layer of synovial epithelium which is attached to the outer surface of the glenoid labrum and the glenoid neck of the scapula (Pfahler et al., 2003). In contrast, Robinson (1922) and Williams (1995) state that it is only attached to the circumferential glenoid margin outside the glenoid labrum. Bain et al. (2012) believe that the external circumferential ridge surrounding the glenoid is for the insertion of the fibrous capsule, which is more obvious posteriorly. Many nutrient foramina are also noted on the capsular circumferential ridge.

The attachment of the fibrous capsule to the glenoid labrum has been classified into three types by Mosely and Overgaard (1962): type I attaches to the glenoid labrum; type II inserts at the interface of the glenoid rim and the glenoid labrum; while type III attaches more proximally. Using this classification Park et al. (2000) observed the insertion of the anterior capsule to be type I in 63% (n=68), type II in 20% (n=22) and type III in 17% (n=18), while the insertion of the posterior capsule was type I in 60% (n=65), type II in 31% (n=33) and type III in 9% (n=10). The capsule attaches superior to the base of the coracoid process, therefore it envelopes the proximal attachment of the long head of biceps brachii to the supraglenoid tubercle within the glenohumeral joint (Moore et al., 2010). Furthermore, on the scapula the capsule attaches to the rim of the glenoid cavity just external to the glenoid labrum at the anterior and inferior aspects, creating pouches or recesses between the capsule externally and glenoid labrum internally, which could be significant in glenohumeral joint pathology. Anterior capsular redundancy of the glenohumeral joint, i.e. leaving a pouch, is seen in arthroscopic examination of the glenohumeral joint following recurrent anterior dislocation.

To determine whether this capsular redundancy is congenital or post-traumatic Uhthoff and Piscopo (1985) investigated 52 foetal glenohumeral joints between 7 and 22 weeks gestation. They found that 77% (n=40) joints showed that the anterior part of the fibrous capsule was attached to the glenoid labrum, while the remaining 23% (n=12) attached to the scapular neck only, allowing the existence of a pouch: the glenoid labrum was attached to the underlying bone: the authors concluded that the presence of a pouch is not necessarily due to trauma. Furthermore, all the posterior part of the fibrous capsule was attached to the posterior glenoid labrum (Uhthoff and Piscopo, 1985) leading to the formation of a posterior synovial fold in 2% (n=8) of cases, which is more predominant in females (Novak et al., 2009). In contrast, the fibrous capsule is said to be attached directly to the glenoid labrum at the posterior and inferior aspects (Palastanga et al., 2006). The capsular fibres run in a spiral manner from proximal to distal with their concavity facing anteriorly; therefore they become tense in extension and lax in flexion: this determines the limitation of extension at the joint to 90^0 while allowing free flexion to 180^0 (Smith et al., 1983). However, it has been stated that the majority of capsular fibres run transversely with some passing obliquely (Palastanga et al., 2006). Capsular fibre orientation influences movement of the glenohumeral joint: with the arm in the anatomical position the orientation is forward and medially twisted, which is increased in abduction and decreased in flexion (Peat, 1986).

The capsule is strong and lax to allow free movement of the joint, being thickened distally by fusion of the short scapular muscle tendons. It also is thickened and strong in some regions, mainly anterior to provide support, without which it could lead to potential instability of the glenohumeral joint. These anterior thickenings are caused by the presence of the glenohumeral ligaments, which are only visible from inside the capsule. The distal part of the posterosuperior region of the capsule is strengthened by the coracohumeral ligament (Sinnatamby, 2006; Palastanga et al., 2006). The poor fit of the joint surfaces is partly compensated for by: (i) reinforcement of the joint capsule by the glenohumeral ligaments and subscapularis tendon anteriorly, (ii) the tendon of supraspinatus superiorly, (iii) the tendons of infraspinatus and teres minor posteriorly, and (iv) inferiorly where it is partially supported by the long head of triceps (Williams, 1995). However, inferior joint dislocation is more likely to occur as there are neither rotator cuff muscles nor capsular reinforcements to the capsule inferiorly (Monkhouse, 2001). In contrast, fibres from subscapularis anteriorly and teres minor posteriorly extend to the level of the anterior and posterior aspects of the axillary pouch at the inferior aspect of the fibrous capsule by which inferior partial stability is achieved (Di Giacomo et al., 2008). In addition, the capsule is maintained taut during movement of the glenohumeral joint due to the rotator cuff tendons blending with it distally superiorly, anteriorly and posteriorly (Smith et al., 1983). The fibrous capsule is strongly attached to the inner surface of the rotator cuff near its insertion on the humerus, becoming loose between the rotator cuff muscles and fibrous capsule and free of attachment between the rotator cuff and the fibrous capsule at the level of the glenoid rim. The fibrous capsule deep to the tendons of supraspinatus and infraspinatus is thickened by a 1 cm wide fibrous band of tissue which passes to the posterior edge of infraspinatus and appears to be a deep continuation of the coracohumeral ligament running through the interval between the fibrous capsule and rotator cuff tendons (Di Giacomo et al., 2008).

The fibrous capsule is thickened in the interval between subscapularis and supraspinatus by approximately 2mm around its attachment to the tubercles of the humerus, but is thinner in the posteroinferior and inferior aspects, being about 1mm. It is believed that one of the reasons there is a strong attachment between the rotator cuff tendons and the fibrous capsule is to ensure that the tension generated, which is provided by the rotator cuff muscles, is powerful enough to retract the redundant part of the inferior aspect of the fibrous capsule in a similar way to which articularis genu does to the suprapatellar pouch at the knee joint. Some studies (Delorme, 1910; DePalma et al., 1949; Clark et al., 1990; Warner et al., 1992) (cited by Di Giacomo et al., 2008) report that the tendons of the rotator cuff muscles merge with each other and with fibres of the glenohumeral joint capsule reinforcing it and making it appear as one structure. It is obvious that the rotator cuff tendons not only provide support to the fibrous capsule, but also the capsular fibrous bands: in particular the transverse superficial fibrous band gives some support to the rotator cuff tendons by holding them together therefore any tensile force can be dissipated and thus protect them from tearing at their distal insertion. At least half the fibrous capsule is reinforced from the surrounding muscles with supraspinatus and subscapularis being the strongest, while the long head of triceps, infraspinatus and teres minor also contribute (Delorme, 1910; DePalma et al., 1949; Clark et al., 1990; Warner et al., 1992) (cited by Di Giacomo et al., 2008). The joint capsule varies in thickness from 1.32 to 4.47 mm, with the proximal part being thicker (mean 3.03 mm at the glenoid side) compared to the lateral part (mean 2.17mm at the humeral side) (Ciccone et al., 2000).

The fibrous capsule is a complex structure and has many functions, being reinforced by several superficially oriented fibrous bands. It provides support to the inner synovial membrane lining, restraint, a watertight seal and an extension insertion to the periarticular tendons (Di Giacomo et al., 2008). According to Ishihara et al. (2014) the superior fibrous capsule provides stability to the joint with any tear in it, which could be associated with some rotator cuff tear cases, significantly increasing humeral head translation in all directions. The other function of the fibrous capsule is the tension produced by the rotator cuff tendons in which release of the superior capsule, with or without the coracohumeral ligament, could help in the repair of a rotator cuff tear. Hatakeyama et al. (2001) created a rotator cuff tear and then repaired it, with the strain on the repaired tendon measured after either release of the superior capsule or the coracohumeral ligament, or both. The average tension decreased by 25% in abduction if either was released and up to 44% if both were released. The superior aspect of the fibrous capsule prevents inferior dislocation of the joint during adduction (Basmajian and Bazant, 1959).

The blood supply to the fibrous capsule is from the anterior and posterior circumflex humeral arteries laterally and the suprascapular and circumflex scapular arteries medially, in addition to muscular branches from the rotator cuff muscles. However, some individuals show a hypovascular zone associated with the anterior aspect of the fibrous capsule close to its humeral insertion (Andary and Petersen, 2002).

Five distinctive histological layers have been observed, including the superior aspect of the rotator cuff and the fibrous capsule. The first layer is a thin fibrous layer just underneath the synovial layer which is arranged in an interwoven manner. The second layer is thick and consists of the actual fibrous capsule as well as fibres of the coracohumeral ligament extending along the interval of the rotator cuff, which are considered as being part of the roof for the tendon of long head of biceps, between subscapularis, supraspinatus and up to 1 cm beneath the two tendons. The third layer consists of loose tendinous fibres which become more dense distally towards their insertion: its function is to connect the capsular layer to the internal layer of the rotator cuff tendons. The fourth layer is considered to be the actual tendon layer which consists of fibrous bundles of the tendon of supraspinatus which connects to the tendon of infraspinatus as well as to the long head of biceps canal exit. The anterior aspect of the supraspinatus tendon is denser and stronger and overlapped by the tendon of subscapularis on its superolateral aspect, which is thought to provide extra support around the rotator interval. The fifth layer is a superficial fibrous layer external to the tendon of supraspinatus running from the coracoid process (Clark et al., 1990; Yamazaki, 1990; Clark and Harryman, 1992; Gohlke et al., 1994; Gagey et al., 1993; Cooper et al., 1993b).

2. Synovial membrane:

Synovial membrane lines the interior surface of the loose fibrous layer of the joint capsule (Smith et al., 1983) and attaches to the margin of the articular surfaces of the glenoid cavity medially and head of the humerus laterally (Drake et al., 2005) (Figure 2.2.1). The synovial membrane is reflected interiorly at the glenoid labrum and humeral head to the articular margins of both sides (Schafer and Thane, 1892; Moore et al., 2010). Inferiorly, it covers the bare area of the surgical neck of the humerus, which is intracapsular (Sinnatamby, 2006), extending to cover the region of the medial side of the humeral shaft between the articular cartilage and the inferior attachment of the joint capsule (Smith et al., 1983). The epiphyseal line of the medial part of the shaft is intracapsular but extrasynovial (Palastanga et al., 2006). Inferiorly the synovial membrane is redundant in the anatomical position, being stretched when the arm is abducted (Drake et al., 2005). It is reflected as a double-layered (Palastanga et al., 2006) cylindrical sheath to invest the long head of biceps brachii within the glenohumeral joint (Moore et al., 2010). The cylinder of synovial membrane also provides a double layer surrounding the tendon of the long head of biceps brachii as it runs inferior to the transverse humeral ligament in the intertubercular sulcus, extending 2 cm into the arm (Smith et al., 1983; Palastanga et al., 2006). The main function of the synovial membrane surrounding the tendon of the long head of biceps brachii is to permit gliding when the arm is adducted and abducted (Sinnatamby, 2006).

Through openings in the fibrous capsule the synovial membrane gives rise to bursae between it and the tendons of the surrounding muscles. The subtendinous bursa of subscapularis is located between the fibrous capsule posteriorly and tendon of subscapularis anteriorly (Drake et al., 2005). A variable extension of the synovial membrane forming the subscapularis bursa may extend to reach the coracoid process superiorly; it may be replaced by a separate bursa, the subcoracoid bursa, while an extension posteriorly gives rise to the infraspinatus bursa (Palastanga et al., 2006). There are other bursae related to the glenohumeral joint, but not directly connected to the joint cavity: for example the subacromial bursa lies superior to the glenohumeral joint between supraspinatus and deltoid (Drake et al., 2005). Both Ellis (2006) and Abrahams et al. (2011) are of the view that the synovial membrane communicates with the subscapularis bursa only. However, they are of the view that the joint capsule has two openings, the first between the lesser and greater tubercles of the humerus allowing passage of the tendon of the long head of biceps brachii (Moore et al., 2010); in this region the capsule is thickened giving rise to the transverse humeral ligament which arches over the tendon attaching to the margins of the inter-tubercular sulcus converting it to a canal (Palastanga et al., 2006). The second opening lies anteroinferior to the coracoid process of the scapula (Moore et al., 2010), between the superior and middle glenohumeral ligaments (Palastanga et al., 2006), allowing direct communication between the synovial cavity of the glenohumeral joint and the subscapular bursa beneath the tendon of subscapularis (Moore et al., 2010). A third bursa may be present situated posteriorly providing communication between infraspinatus and the joint cavity (Palastanga et al., 2006).

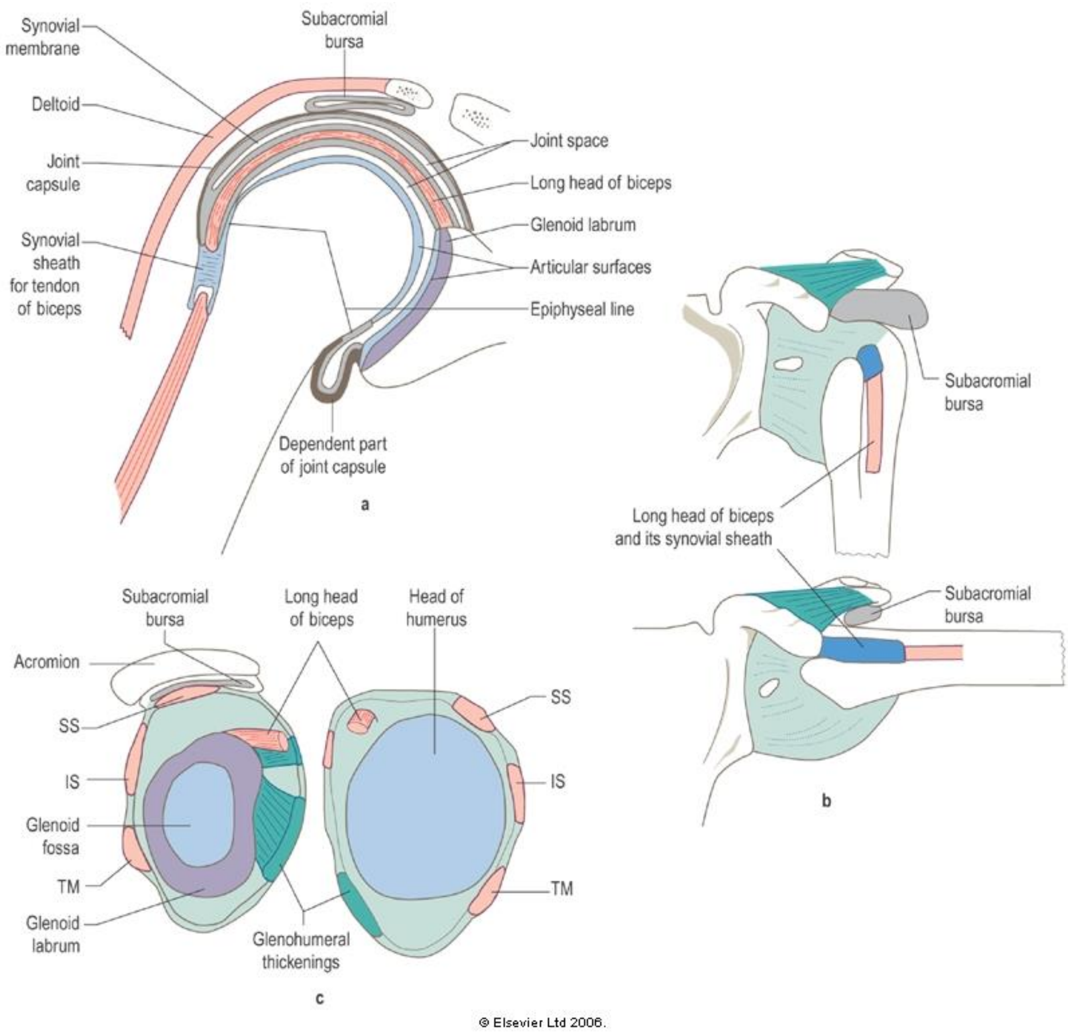


Figure 2.2.1: (A) Coronal section of the shoulder joint showing the reflection of the synovial membrane around the long head of biceps, (B) withdrawal of the subacromial bursa and protrusion of the biceps synovial sheath from the joint capsule when the arm is abducted, (C) the joint opened out, also showing the blending of some of the rotator cuff muscles to the capsule, IS, infraspinatus; SS, supraspinatus; TM, teres minor, [Palastanga et al. (2006) Anatomy and Human Movement, 5th edition]

3. Bursae

The glenohumeral joint is surrounded by several bursae, defined as sac-like cavities filled with capillary films of synovial fluid secreted by the synovial membrane of the joint capsule (Moore et al., 2006). There are two large bursae around the glenohumeral joint, the subscapular and subacromial (Faiz and Moffat, 2006; Ellis, 2006), although others mention three bursae, the subscapularis, subacromial and infraspinatus bursae (Sinnatamby, 2006). These bursae are classified as communicating with the joint cavity (e.g. subscapularis bursa) or not communicating with the joint cavity (e.g. subacromial bursa) (Drake et al., 2005). Generally, bursae prevent friction between a tendon and bone, or where ligaments, tendons and skin moves over a prominent bone (Moore et al., 2010). Their function is to decrease, rather than prevent, the friction between tendons and the joint capsule (Drake et al., 2005). However, the bursae around the glenohumeral joint are especially important because there is direct communication between the subscapularis bursa and the joint cavity, which means that any tear to this bursa provides an opening to the synovial cavity (Moore et al., 2010).

Bursae communicating with the joint cavity:

Subscapular bursa:

The subscapular bursa, also known as the subtendinous bursa of subscapularis, lies between the tendon of subscapularis anteriorly and the neck of the scapula posteriorly (Robinson, 1922; Lumley et al., 1995; Abrahams et al., 2010; Moore et al., 2010) or subscapularis and the fibrous joint capsule (Drake et al., 2005). It may have a variable extension (Schafer and Thane, 1892), but is constant in its position with its lining membrane being continuous with the synovial lining of the fibrous capsule (Robinson, 1922). Furthermore, it provides a cushion and facilitates movement of the subscapularis tendon as it passes to attach to the root of the coracoid process of the scapula (Moore et al., 2010). It has a direct communication with the glenohumeral joint cavity via an aperture in the synovial layer of the joint capsule (Moore et al., 2010) between the superior and middle glenohumeral ligaments (Gray et al., 1946; Sinnatamby, 2006; Palastanga et al., 2006): it is therefore an extension of the glenohumeral joint cavity (Moore et al., 2010). A similar bursa is occasionally seen posterosuperiorly, intervening between the fibrous capsule and tendon of infraspinatus (Robinson, 1922; Gray et al., 1946).

Bursae not communicating with the joint cavity:

Subacromial bursa:

The subacromial, also referred to as the subdeltoid, bursa is large (Sinnatamby, 2006) intervening between the supraspinatus tendon and joint capsule inferiorly, and the acromion, coracoacromial ligament and deltoid superiorly (Robinson, 1922; Lumley et al., 1995; Moore et al., 2010) (Figure 2.2.1). However, it has been stated that the subacromial bursa is located between supraspinatus, deltoid and the joint capsule and does not communicate with the glenohumeral joint cavity (Drake et al., 2005). The subacromial bursa is located below the acromion and coracoacromial ligament superior to the supraspinatus tendon: the superior and inferior layers of the subacromial bursa are attached to the coracoacromial ligament and supraspinatus respectively (Robinson, 1922; Sinnatamby, 2006). The supraspinatus tendon lies in the floor of the bursa (Faiz and Moffat, 2006). The subacromial bursa projects laterally with the arm in the anatomical position and moves medially under the acromion during abduction (Sinnatamby, 2006). When the subacromial bursa extends under deltoid it is named the subdeltoid bursa (Ellis, 2006; Abrahams et al., 2011). The function of the subacromial bursa is to reduce friction during movement of supraspinatus beneath the coracoacromial arch and deltoid over both the joint capsule and greater tubercle of the humerus (Robinson, 1922; Moore et al., 2010). In cases of a supraspinatus tendon tear the subacromial bursa communicates with the joint cavity despite their normally being no communication between them. Moreover, there is an infraspinatus bursa located posterior to the joint capsule which sometimes communicates with the joint cavity (Sinnatamby, 2006): it can be absent, but is always located posteriorly and communicates through the fibrous capsule (Palastanga et al., 2006).

Other bursae:

A large bursa is located on the superior surface of the acromion: another is sometimes present between the coracoid process and scapula. One is often found posterior to coracobrachialis and another between teres major and the long head of triceps. Two bursae, one anterior and one posterior, may be found associated with the tendon of latissimus dorsi (Gray et al., 1946).

4. Rotator interval:

In the fibrous capsule there is a rotator interval, defined as the region between the anterior border of the supraspinatus tendon and the superior border of the subscapularis tendon. The type of rotator interval has been classified by DePalma et al. (1949) as: type I in which the opening is superolateral to the middle glenohumeral ligament; type II in which the opening is inferomedial to the middle glenohumeral ligament; type III in which there are two openings, one superior and one inferior to the middle glenohumeral ligament; type IV in which there is a large opening in association with absence of the middle glenohumeral ligament; type V in which the middle glenohumeral ligament has been manifested as two small rotator interval capsule openings; and type VI in which there is no rotator interval. In a study of 104 patients Wilson et al. (2013) observed the following frequencies of rotator interval: 59% type I, 1% type II, 22% type III, 9% type IV, 0% type V, 7% type VI and 3% Buford complex, which according to Williams et al. (1994) and De Maeseneer et al. (2000) is defined as absence of anterosuperior aspect of the glenoid labrum and cord-like middle glenohumeral ligament. Di Giacomo et al. (2008) describe the rotator interval macroscopically as a complex network of tendinous and ligamentous structures and arthroscopically as a triangular space between the superior and middle glenohumeral ligaments, being a consistent synovial recess occasionally variable in dimensions leading to the subscapularis bursa. They emphasize that according to the pathological condition, the rotator interval can have two forms: in rotator cuff tears it is a tendinous connection between subscapularis and supraspinatus, while in glenohumeral joint instability it is a triangular slot in the fibrous capsule between the superior glenohumeral ligament superiorly and the middle glenohumeral ligament inferiorly. Jost et al. (2000) report that it is composed of subscapularis, supraspinatus, the superior glenohumeral ligament and the coracohumeral ligament, as well as the glenohumeral fibrous capsule. Its proximal part consists of two layers while the distal part consists of four layers. According to Di Giacomo et al. (2008) the distal four layers are: (1) the superficial fibres of the coracohumeral ligament that cover the rotator interval extending as far as the insertion of supraspinatus and subscapularis; (2) a network formed by some fibres of the supraspinatus and subscapularis tendons which merge together and with the coracohumeral ligament; (3) the deep fibres of the coracohumeral ligament; and (4) the superior glenohumeral ligament as well as the fibrous capsule. The proximal two layers are: (1) the coracohumeral ligament and (2) the superior glenohumeral ligament and the fibrous capsule. In addition, Kolts et al. (2002) state that the rotator triangle has lateral, mediosuperior and medioinferior aspects: the semi-circular humeral ligament and tendon of supraspinatus support the lateral part, the superior and middle glenohumeral ligaments support the medioinferior aspect, while the coracohumeral and glenocoracoid ligaments form the mediosuperior aspect. Fealy et al. (2000) reported that the rotator interval was consistent in all foetal specimens at 14 weeks gestation.

The function of the rotator interval with respect to glenohumeral joint stability has been evaluated on cadaveric models. Sectioning it increases joint laxity in flexion, extension, external rotation and adduction: imbrication also decreases inferoposterior translation (Harryman et al., 1992). The medial aspect of the rotator interval, especially the coracohumeral ligament, secures inferior translation during adduction as well as external rotation, whereas its lateral aspect helps to control humeral head translation in external rotation of the adducted arm (Di Giacomo et al., 2008). In patients with multidirectional instability Field et al. (1995) reported a hole in the rotator interval, which after closure, provided adequate stability. Rowe and Zarins (1981) also noted a hole in the rotator interval of the fibrous capsule in 20 of 37 patients who underwent open surgery for glenohumeral joint stability. Kim et al. (2004) demonstrated that closure of the rotator interval in constant inferior glenohumeral instability, as well as failure to identify the defect in the rotator interval, might lead to recurrent glenohumeral instability. Jost et al. (2000) reported that the rotator interval limits inferior humeral head translation in adduction and external rotation.

5. Synovial recess and sublabral recesses:

Synovial recess:

The synovial (labral) recess is defined as a separation between the long head of biceps tendon and the underlying superior glenoid labrum: it is lined by synovial membrane (Bain et al., 2012). DePalma et al. (1949, 1967) classified the synovial recess according to the variability of the glenohumeral ligaments in which the synovial recess superior to the middle glenohumeral ligament is the superior subscapularis recess and that inferior is the inferior subscapularis recess: the difference in dimension between both recesses varies widely becoming smaller with age. Six types of synovial recess have been identified: type I is a single recess superior to the middle glenohumeral ligament; type II is a single recess inferior to the middle glenohumeral ligament; type III has two recesses, one superior and one inferior to the middle glenohumeral ligament; type IV is a single large recess superior to the inferior glenohumeral ligament; in type V the middle glenohumeral ligament becomes two small synovial folds; and in type VI there are no recesses (DePalma et al., 1949; DePalma et al., 1967) (cited in Di Giacomo et al., 2008). A subscapular bursa is present in 80 – 89% of the population extending from the superior aspect of the tendinous edge of subscapularis to the inferior surface of the coracoid process opening into the superior subscapular recess. It functions as a gliding mechanism for the subscapularis tendon and coracoid process (Moseley and Overgaard, 1942; Colas et al., 2004). Park et al. (2000), using MRI arthrograms, reported a labral recess in 30% (n=32) of joints examined. Recently, two additional synovial recesses have been added: the posterior and axillary recesses (Jacobson, 2013).

The glenohumeral joint has many synovial recesses which may become distended in any joint pathology that increases its fluid content. For example, the synovial recess at the long head of biceps tendon becomes distended in biceps tenosynovitis (Jacobson, 2013).

Sublabral recesses:

Using MR arthrography, multi-slice CT arthrography, anatomical dissection and the Smith et al. (1996) classification, which consists of type I, a firm attachment of the superior labrum to the glenoid rim, type II which shows a recess not deeper or equal to 2mm, type III which has a recess ranging between 2 - 5 mm, and type IV which has a recess deeper than 5mm and in which the superior labrum is meniscoid in shaped.

Waldt et al. (2006) found that in anatomical dissection only 74% (n=32) of specimens revealed a sublabral recess, being type I in 23% (n=10), type II in 19% (n=8), type III in 23% (n=10) and type IV in 33% (n=14). Compared with dissection MRI demonstrated a sublabral recess in 60% (n=26) suggesting that the sensitivity, specificity, accuracy and negative and positive predictive values of MRI in detecting a sublabral recess are 81%, 100%, 86%, 65% and 100% respectively. Compared to dissection CT arthrography demonstrated sublabral recesses in 63% (n=27) giving a sensitivity, specificity, accuracy and negative and positive predictive values of CT arthrography in detecting a sublabral recess as 84%, 100%, 88%, 69% and 100% respectively. The accuracy in the detection of sublabral recesses using MRI and CT arthrography is 59% and 81% respectively, with no significant difference between them. In addition, five sublabral holes and one Buford complex were revealed by both MR and CT arthrography. Dividing the superior labrum into three segments; anterior (between 10 - 11 o'clock), central (between 11 - 1 o'clock) and posterior (between 1 - 2 o'clock) sublabral recesses are found anteriorly (13%, n=4), centrally (19%, n=6), posteriorly (6%, n=2), anteriorly and centrally (38%, n=12), centrally and posteriorly (3%, n=1) and in all segments (22%, n=7) (Waldt et al., 2006).

Section 3: Ligaments of the glenohumeral joint

1. Capsular ligaments:

The anterior region of the glenohumeral joint capsule is strengthened by fibrous bands running transversely between its proximal and distal attachments. These are the glenohumeral ligaments (superior, middle and inferior) (Figure 2.3.1), which can only be seen on the internal aspect of the joint capsule (Palastanga et al., 2006) by opening the posterior aspect of the fibrous capsule and removing the humeral head (Gray et al., 1946). They originate proximally from the superior aspect of the medial margin of the glenoid cavity and are intimately connected to the glenoid labrum at the supraglenoid tubercle radiating laterally and inferiorly to merge with the fibrous layer of the joint capsule as it attaches to the anatomical neck of the humerus distally (Gray et al., 1946, Moore et al., 2010). However, Robinson (1922) clearly states that they arise from the anterior aspect of the glenoid cavity and insert into the anterior aspect of the humeral neck. According to Drake et al. (2005) the glenohumeral ligaments arise proximally only from the superomedial margin of the glenoid cavity and insert distally to the lesser tubercle and anatomical neck of the humerus.

Superior glenohumeral ligament:

According to Di Giacomo et al. (2008) the first person to use the term superior glenohumeral ligament was Flood (1829). The superior glenohumeral ligament is slender originating proximally just anterior to the origin of the tendon of long head of biceps brachii and superior to the opening in the anterior capsule, from the superior margin of the glenoid cavity, the adjacent glenoid labrum (Robinson, 1922; Gray et al., 1946) (Figure 2.3.1) and base of the coracoid process, subjacent to the coracoacromial ligament (Williams, 1995), with some fibres coming from the supraglenoid tubercle anterior to the origin of the long head of biceps tendon, some from the long head of biceps brachii and the middle glenohumeral ligament, which are occasionally intertwined (Di Giacomo et al., 2008). It passes along the medial side of the origin of the long head of biceps brachii and runs laterally parallel and anterior to the tendon accompanied by a small artery, where it has the appearance of a synovial fold in the interior aspect of the fibrous capsule, to attach to the superior surface of the lesser tubercle of the humerus distally (Palastanga et al., 2006; Di Giacomo et al., 2008).

However, there appears to be some controversy concerning its attachment. Some state that it arises from the base of the coracoid process as well as the superior aspect of the glenoid labrum (Williams, 1995); while others state that it originates from the glenoid neck close to the origin of the long head of biceps tendon (Di Giacomo et al., 2008). Kask et al. (2010) observed the superior glenohumeral ligament to divide into direct and oblique fibres: in 92.5% (n=25) of specimens the oblique fibres arose as a common origin with the middle glenohumeral ligament from the supraglenoid tubercle. The middle glenohumeral ligament was absent in 7% (n=2) of cases; however the superior glenohumeral ligament oblique fibres originated with the direct fibres from the anterosuperior aspect of the glenoid labrum. In contrast all the direct fibres originated directly from the glenoid labrum between 11 and 1 o'clock and were partially covered by fibres of the middle glenohumeral ligament in 92.5% (n=25). The direct fibres passed laterally between the long head of biceps and subscapularis tendons undercover of the coracohumeral ligament to insert mainly into the floor of the bicipital groove and partly into the lesser tubercle whereas the oblique fibres ran superior to the long head of biceps tendon to insert in the semicircular humeral ligament (rotator cable) (Kask et al., 2010). Earlier Kolts et al. (2001) observed that the superior glenohumeral ligament arose from the supraglenoid tubercle and inserted into the lesser tuberosity. The humeral attachment of the superior glenohumeral ligament is the anterior area located between the lesser tubercle and the articular margin (Williams, 1995). Moreover, it has been clearly stated that it inserts into a small depressive area on the humeral articular surface (Di Giacomo et al., 2008).

Middle glenohumeral ligament:

The middle glenohumeral ligament originates proximally just inferior to the superior ligament from a wide area along the anterior margin of the glenoid as far inferiorly as the inferior third of the rim (Figure 2.3.1), where it runs downwards and laterally to attach to the anterior surface of the lesser tubercle of the humerus, deep to the tendon of subscapularis, with which it merges distally (Williams, 1995; Palastanga et al., 2006). Through the space between the superior and middle glenohumeral ligaments the subscapularis bursa communicates with the joint cavity (Sinnatamby, 2006).

There is some disagreement between studies regarding the attachment of the middle glenohumeral ligament. In a study of 22 fresh frozen shoulders and 49 arthroscopic shoulders the middle glenohumeral ligament arose from the superior neck of the scapula and anterosuperior glenoid labrum and fused with the lateral aspect of the anterior region of the fibrous capsule: it was absent in 13.6% (n=3) shoulders (Merila et al., 2008). Kolts et al. (2001) reported that the middle glenohumeral ligament arose from the supraglenoid tubercle, anterosuperior aspect of the glenoid neck of the scapula and the base of the coracoid process and inserted into the lesser tuberosity. According to Gray et al. (1946) the humeral attachment of the middle glenohumeral ligament is the inferior aspect of the lesser tubercle.

Inferior glenohumeral ligament:

In contrast to both the superior and middle glenohumeral ligaments the inferior glenohumeral ligament is more prominent, ambiguous, longer and stronger. Proximally, it originates from the anterior margin of the glenoid cavity inferior to the glenoid notch and the anterior border of the glenoid labrum (Robinson 1922; Gray et al., 1946; Palastanga et al., 2006) (Figure 2.3.1). It passes inferolaterally to attach to the anteroinferior aspect of the anatomical neck of the humerus distally (Robinson 1922; Gray et al., 1946; Palastanga et al., 2006) and the inferomedial aspect of the humeral neck (Williams, 1995). The superior edge of the inferior glenohumeral ligament may blend with the inferior edge of the middle glenohumeral ligament. The ligament may be absent (Robinson 1922; Gray et al., 1946; Palastanga et al., 2006).

The inferior glenohumeral ligament consists of anterior and posterior bands, with an axillary pouch between (Ticker et al., 2006). In an evaluation of 51 foetal shoulders the anterior capsule was thicker than that posteriorly. During week 14, the inferior glenohumeral ligament is more prominent than the superior and middle ligaments. Distinct anterior and posterior bands of the inferior glenohumeral ligament with the axillary pouch between can be clearly seen, with the anterior band attaching to the glenoid labrum between 2 - 4 o'clock and the posterior band between 8 and 9 o'clock (Fealy et al., 2000). The anterior band arose from the anterosuperior glenoid labrum at 3 o'clock or above in 33.33% (n=4) of shoulders, from the middle glenohumeral ligament in 8.33% (n=1) and from the anteroinferior glenoid labrum in 41.66% (n=5) (Ruiz et al., 2012). In contrast Gelber et al. (2006) reported the anterior band of the inferior glenohumeral ligament arising from the glenoid rim midway along the anterior border being more prominent in external rotation; however, the posterior band was only found in 25/61 (41%) shoulders. The inferior glenohumeral ligament attaches to the humeral neck in the form of a collar in 41% (n=25), to the humerus with an inferior angulation giving rise to a V-shape axillary pouch in 36% (n=22), while in 23% (n=14) it was not well defined (Gelber et al., 2006). The thickness of the inferior glenohumeral ligament due to contraction of the fibrous capsule is debated: 20 patients' shoulders with fibrous capsular contraction were studied by ultrasound and the findings compared with the contralateral normal shoulder; 20% (n=4) showed a significant difference ($P<0.0001$) in thickness, being 4 mm in the capsular contracted inferior glenohumeral ligament and 1.3 mm in normal shoulders (Michelin et al., 2013).

There is also variation in the attachments of the inferior glenohumeral ligament. Kolts et al. (2001) state that it originates from the scapular neck and base of the coracoid process just inferior to the middle glenohumeral ligament and inserts into the surgical neck of the humerus. However, others report that it originates from the anterior margin of the glenoid cavity inferior to the glenoid notch and anterior border of the glenoid labrum (Robinson 1922; Gray et al., 1946; Palastanga et al., 2006), while Williams (1995) reported that the inferior glenohumeral ligament arises from the anterior, middle and posterior margins of the glenoid labrum only. One study revealed that the inferior glenohumeral ligament is attached firmly into the glenoid rim as well as to the anteroinferior aspect of the glenoid labrum (at 4 o'clock) (Cooper et al., 1992).

The presence of the three glenohumeral ligaments is variable. In an MRI arthrogram study the superior and inferior glenohumeral ligaments were observed in 99% (n=107), while the middle glenohumeral ligament was observed in only 79% (n=85) (Park et al., 2000). Dewan et al. (2012) reported variations of the superior glenohumeral ligament in 7.84% (n=4), of the middle glenohumeral ligament in 9.8% (n=5) and of the inferior glenohumeral ligament in 17.64% (n=9) of individuals. However, Wilson et al. (2012) observed the superior glenohumeral ligament in all shoulders examined and the middle glenohumeral ligament in only 88% (n=91). The superior glenohumeral ligament appears to be consistently observed (Delorme, 1910; Welcker, 1877; Fick, 1904 (cited in Di Giacomo et al., 2008)).

In a study correlating MRI observations in 10 cadaveric shoulders, the superior glenohumeral ligament was seen in 10% (n=1), the middle glenohumeral ligament in 30% (n=3) and the inferior glenohumeral ligament in 40% (n=4) (Longo et al., 1996). While in a study of 22 fresh frozen and 49 arthroscopic shoulders a spiral glenohumeral ligament arising from the infraglenoid tubercle and tendon of the long head of triceps brachii passing superoanterolaterally anterior to the middle and inferior glenohumeral ligaments and fusing with the tendon of subscapularis to insert together in the lesser tuberosity of the humerus was observed in all specimens: the ligament was found to become taut during abduction and external rotation of the glenohumeral joint (Merila et al., 2008). In an arthroscopic study a spiral glenohumeral ligament was seen in 45% (n=22) shoulders, the middle glenohumeral ligament in 88% (n=43) and the inferior glenohumeral ligament in 94% (n=46) (Merila et al., 2008). A macroscopic dissection, histology and radiology revealed that the caspular-ligamentous complex and the synovium showed no age-related differences (Pfahler et al., 2003).

Extra glenohumeral ligament:

An additional glenohumeral ligament has been observed by Kolts et al. (2001) in the anterior layer of the fibrous capsule arising from the axillary pouch of the inferior glenohumeral ligament and inserting into the superolateral aspect of the tendon of subscapularis.

Function of the glenohumeral ligaments:

The function of the glenohumeral ligaments has been evaluated by a number of investigators. The superior glenohumeral ligament stabilizes the glenohumeral joint in adduction and external rotation; the middle glenohumeral ligament stabilizes the joint in adduction, external rotation and abduction up to 45^0; while the inferior glenohumeral ligament supports the joint in adduction and adduction in external rotation between 45^0

and 90^0 (Felli et al., 2012). Despite the ligaments tending to become taut during movement of the glenohumeral joint, for example lateral rotation of the humerus makes all three glenohumeral ligaments taut, whereas medial rotation relaxes them, while in abduction of the humerus the inferior and middle glenohumeral ligaments become taut while the superior relaxes. Nevertheless the glenohumeral ligaments have a variable and inconsistent role in contributing to joint stability (Palastanga et al., 2006).

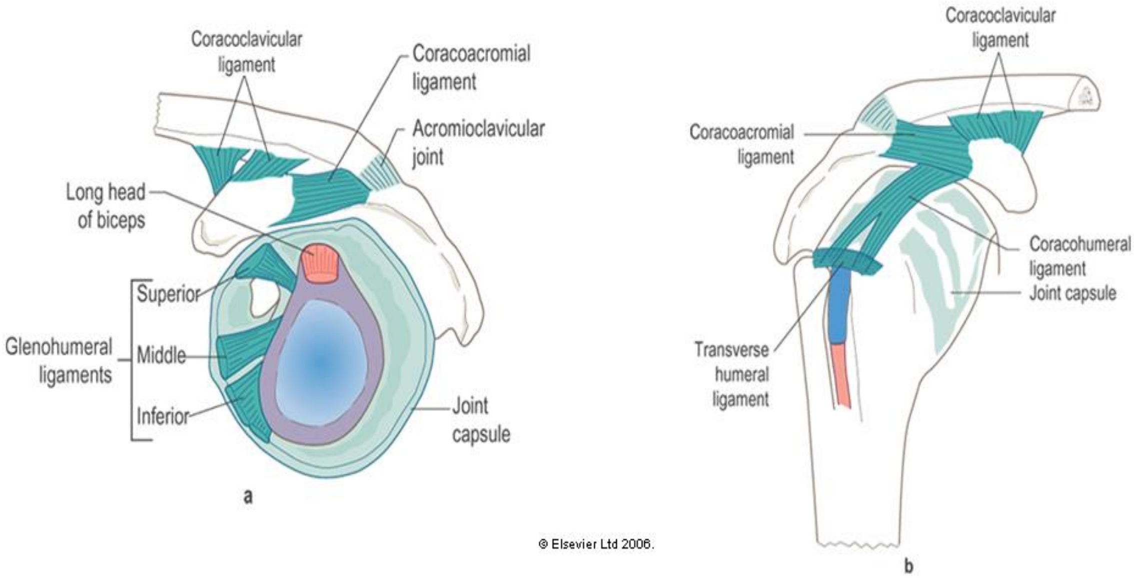


Figure 2.3.1: Shoulder joint capsule: (A) lateral view of glenoid fossa with the head of humerus removed to show the glenohumeral ligaments, (B) transverse humeral ligament. Palastanga et al. (2006) Anatomy and Human Movement, 5th edition.

2. Transverse humeral ligament:

The capsule is thickened at the lateral posterosuperior aspect of the joint giving rise to the transverse humeral ligament (Palastanga et al., 2006), a broad fibrous band passing obliquely (Moore et al., 2010). It arches anteriorly over the intertubercular sulcus between the lesser and greater tubercles of the humerus (Palastanga et al., 2006), converting it into a canal (Moore et al., 2010), holding the tendon of the long head of biceps brachii (Drake et al., 2005) and its synovial sheath (Moore et al., 2010) within the sulcus as it emerges from the joint (Drake et al., 2005) (Figure 2.3.1). Brodie (1899) described it as a broad band of fibrous tissue, trapezoid in shape running between the lesser and greater tubercles of the humerus attaching to the area of bone just superior to the epiphyseal line of the humerus. The authors have also observed that the transverse humeral ligament is more marked in the foetal glenohumeral joint and thought that it is a purely cartilaginous structure in early foetal life, which then degenerated to become fibrocartilaginous and finally fibrous. The function of the transverse humeral ligament is to prevent dislocation of the long head of biceps tendon during movement (Brodie, 1899).

The presence of the transverse humeral ligament is still unclear and confusing. Bond et al. (2005) are of the view that it does not exist, explaining that the presence of fibrous tissue between the humeral tubercles is due to an interdigitation of two sets of fibres: the superficial part of the subscapularis tendon, which continues to attach to the greater tubercle, and the anterior fibres of supraspinatus tendon as well as the coracohumeral ligament. Gleason et al. (2006) support this view stating that what was found were fibres extending from the superficial part of the subscapularis tendon, the tendon of supraspinatus and the coracohumeral ligament: histologically it was confirmed that there is absence of elastin fibres which should be seen in any ligamentous structure. MacDonald et al. (2007) also support this stating that what was identified in all shoulders studied was a fibrous expansion from the posterior lamina of pectoralis major tendon covering the tendon of the long head of biceps brachii. In 86% (n=73) of specimens examined, the fibres from the tendon of subscapularis passed over the tendon of the long head of biceps brachii, inserting into the greater tubercle of the humerus, whereas in 33% (n=28) of dissections, it was observed to run underneath the tendon of the long head of biceps attaching either in the bicipital sulcus or the greater tubercle of the humerus. Macroscopic and microscopic meta-analysis has concluded that there is no transverse humeral ligament (Tarta-Arsene et al., 2011).

However, a recent histological study of the transverse humeral ligament concluded that it consisted of two layers, superficial and deep. The superficial layer is thin and consists of distinct bundles of fibres while the deep layer is fibrous tissue extending between the two edges of the intertubercular groove. The proximal part of the deep layer is a continuation of the supraspinatus tendon and the coracohumeral ligament, while the distal part is formed by fibres from the subscapularis tendon. The golden chloride stain used revealed free myelinated and unmyelinated nerve fibres, but no mechanoreceptors. Based on these finding Snow et al. (2013) concluded that it is a true ligament.

3. Accessory ligaments:

In addition to the capsular ligaments, there are two accessory ligaments associated with the glenohumeral joint. The first is the coracohumeral ligament, which attaches to the coracoid process and runs laterally to merge with the joint capsule (Palastanga et al., 2006); the second is the coracoacromial ligament, which extends from the coracoid to the acromion process of the scapula. However, Smith et al. (1983) do not consider these accessory ligaments of the glenohumeral joint.

4. Coracohumeral ligament:

The coracohumeral ligament is variable, being a relatively strong band attaching to the lateral border of the coracoid process near the base (Palastanga et al., 2006) or directly to the base (Moore et al., 2010) (Figures 2.3.1, 2.3.2). It is wider medially tapering as it passes laterally where it divides into two bands superior to the intertubercular sulcus to attach around the anatomical neck of the humerus at its superior region between the lesser and greater tubercles interlacing with the transverse humeral ligament (Palastanga et al., 2006): Moore et al. (2010) state that it inserts into the anterior aspect of the greater tubercle. The anterior border of the proximal part of the coracohumeral ligament is unattached, while distally it binds to the subscapularis tendon as it merges with the joint capsule before attaching to the lesser tubercle: the posterior border unites with the supraspinatus tendon as it inserts into the greater tubercle (Palastanga et al., 2006). Yang et al. (2009) observed the coracohumeral ligament consistently arising from the lateral aspect of the base of the coracoid process and variably inserting into the tendon of supraspinatus (42.3%, n=11), the rotator interval (42.3%, n=11), both supraspinatus and subscapularis tendons (11.5%, n=3) and solely into the subscapularis tendon (3.9%, n=1). Histologically, it resembles the fibrous capsule rather than a ligament (Yang et al., 2009). According to Schlemm (1853) (cited in Di Giacomo et al., 2008) the coracohumeral ligament consists of two distinctive bands, a superior band, which is stronger and arises from the lateral aspect of the coracoid process and inserting into the posterior margin of the bicipital groove, and an anterior band, which is weaker and arises from the superior glenoid rim and glenoid labrum very close to the origin of the long head of biceps tendon, and inserts into the anterior margin of the bicipital groove: it runs between the supraspinatus and subscapularis tendons. The coracohumeral ligament also shares in the formation of the boundary of the rotator interval (Jost et al., 2000). Kocher (1870) (cited by Di Giacomo et al., 2008) reported that the coracohumeral ligament is Y-shaped arising from the base of the coracoid process just anterior to the origin of the long head of biceps tendon and then divides into two limbs: a weaker posterosuperior limb which attaches to the greater tuberosity with some fibres merging with the supraspinatus tendon adjacent to the insertion and others attaching inferiorly to the fibrous capsule, and a stronger anteroinferior limb which inserts into the lesser tuberosity with some fibres running inferiorly to attach to the fibrous capsule. Moreover, more recently the coracohumeral ligament has been observed to consist of two fibrous bands: a superior band arising from the medioposterior surface of the coracoid process and an inferior band from the coracoid process and glenocoracoid ligament. Both bands run laterally undercover of the supraspinatus tendon to insert into a fibrous band extending between the lesser and greater tubercles, named the ligamentum semicirculare humeri by Kolts et al. (2000).

Debierre (1890), Sappey (1866) Testut and Latarjet (1948) (all cited in Di Giacomo et al., 2008) emphasized that the superficial part of the coracohumeral ligament arises from the base of the coracoid process to the greater tuberosity and intertwines laterally with the circular fibres of the joint capsule, whereas the deep part (coracoglenoid ligament) arises from the coracoid process to the supraglenoid tubercle along with the attachment of the long head of biceps and the glenoid labrum. Moreover, Debierre (1890) (cited in Di Giacomo et al., 2008) reported that the deep part fuses with the superficial part and inserts into both tubercles. The deep part corresponds to a continuation to the superior glenohumeral ligament. Di Giacomo et al. (2008) observed two fibrous bands to the coracohumeral ligament: an anterior band from the anterior part of the posterolateral aspect of the coracoid process inserting into the rotator cable (ligamentum semicircular humeri) laterally: some of its fibres intertwine with the superior glenohumeral ligament forming what is known as an internal reflection pulley. The posterior band arises from the base of the coracoid process and attaches to the rotator cable laterally. Meckel (1816) and Langer (1865) (both cited in Di Giacomo et al., 2008) described the ligament as a superior fibrous bundle supporting the fibrous capsule; however as it passes from the coracoid process to the glenoid labrum Meckel named it the glenocoracoid ligament. The glenocoracoid ligament is defined as a strong fibrous band extending from the coracoid process to the supraglenoid tubercle: it was observed in 79% (n=27) of specimens and appeared to be a continuation of the pectoralis minor tendon (Kolts et al., 2000). Di Giacomo et al. (2008) reported variability in the shape of the coracohumeral ligament as it passes from the posterolateral aspect of the coracoid process between the two bands of the coracoacromial ligament having a width between 10 to 25mm.

The location of the coracohumeral ligament can be predicted arthroscopically as it forms a mean angle of 29^0 with the tendon of subscapularis, 59° with the glenoid surface and 29^0 with the long head of biceps tendon (McHale et al., 2013).

Controversially, some authors believe that the coracohumeral ligament is not a true ligament (Cooper et al., 1993a) because it does not have a superficial sheet, no proper bone to bone attachment and has the characteristic of the fibrous capsule histologically. It has a trapezoid shape extending from the root of the coracoid process to the greater and lesser tubercles as well as the bicipital groove. The coracohumeral ligament is mainly taut in flexion, external rotation and during anterior and posterior humeral head translation, becoming slack in abduction and medial rotation (Edelson et al., 1991). Coopers et al. (1993a) report that based on macro and microscopic anatomy the coracohumeral ligament is V-shaped and is a fold of the fibrous capsule located in the rotator interval: the reason being that histologically it does not have organized collagen bundles. However, Neer et al. (1992) found the coracohumeral ligament to be well developed in 93.56% (n=59) of specimens and absent in the remainding 6.34% (n=4): furthermore, its origin was consistently from the base of the coracoid process but its insertion is variable.

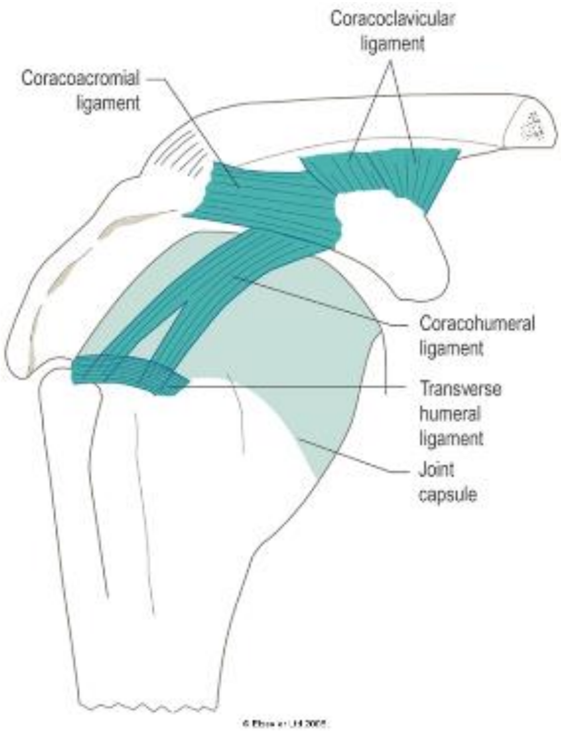


Figure 2.3.2: The coracohumeral and coracoacromial ligaments. Palastanga et al. (2006) Anatomy and Human Movement, 5th edition.

Functions:

The elasticity of the coracohumeral ligament has been assessed by Kijima et al. (2013) who found that its strain ratio without a rotator cuff tear is not significantly correlated with age, while its softness increases significantly in the presence of a rotator cuff tear, i.e. the stiffness increases with age and becomes soft in cases of rotator cuff tears, being softer in asymptomatic rotator cuff tears. The ligament limits external rotation especially in the late cocking phase such that any release to the ligament increases posterior translation of the humeral head: its laxity increases the range of external rotation (Neer et al., 1992; Huffman et al., 2005). Izumi et al. (2011) agree that the coracohumeral ligament strain can be increased significantly in passive external rotation at 0^0 elevation, extension and in extension with adduction. Jost et al. (2000) state that it has a role in external rotation and inferior translation.

5. Coracoacromial ligament:

The coracoacromial ligament is defined as a tense triangular ligament consisting of thick anterior, posterior and thin intermediate borders (Palastanga et al., 2006) (Figures 2.3.1, 2.3.2). Anteriorly, the wide base is attached to the lateral aspect of the transverse part of the coracoid process (Smith et al., 1983), while posteriorly it is attached to the tip of the acromion process just anterior to the acromioclavicular joint (Palastanga et al., 2006). However, Moore et al. (2010) stated that it is attached to the inferior surface of the acromion process, while Sinnatamby (2006) state that it is attached to the medial border of the acromion process of the scapula. It is related to the clavicle and deltoid superiorly (Palastanga et al., 2006), while inferiorly it is separated from the glenohumeral joint and supraspinatus tendon by the large subacromial bursa (Smith et al., 1983): the subacromial space is variable with an average height of 3.9 mm (Di Giacomo et al., 2008).

The shape of the coracoacromial ligament has been observed to be trapezoidal and attached to the inferior aspect of the acromion with a broad reflex portion: its thickness varies between 2 and 5.6mm (Gallino et al., 1995). A prolongation of the tendon of pectoralis minor breaks through the root of the ligament to blend with the coracohumeral ligament (Palastanga et al., 2006). The coracoacromial ligament does not blend with the joint capsule but converts the bony processes, coracoid (anterior) and acromion (posterior) (Palastanga et al., 2006), into a strong flat (Sinnatamby, 2006) fibro-osseous arch superior to the humeral head (Palastanga et al., 2006), which supports and counteracts superior displacement of the head of the humerus against the shallow glenoid fossa and laxity of the joint capsule (Smith et al., 1983), when transmitting forces to the axial skeleton (Palastanga et al., 2006) and preventing superior dislocation of the glenohumeral joint (Moore et al., 2010; Abrahams et al, 2011). A forced trauma pushing the humerus superiorly will not fracture the fibro-osseuos arch, rather the clavicle or humerus is most likely to fracture first (Moore et al., 2010). Soslowsky et al. (1994) reported that the coracoacromial ligament consists of two bands: a longer and thinner medial band and a shorter lateral band which has a larger cross sectional area and is the most likely to impinge on the rotator cuff. Three types of coracoacromial ligament have been observed in neonates: quadrangular, broad and U-shaped (Kopuz et al., 2002).

Recently, five types of coracoacromial ligament have been reported: Y-shaped, quadrangular, broad band, V-shaped and multiple-banded with the Y shaped being the most common (41.3%, n=33): 64% (n=23) of individuals show the same type bilaterally (Kesmezacar et al., 2008). Six types of coracoacromial ligaments have been reported by adding an X-shaped band configuration (Alashkham et al., 2014). Two most common types of the coracoacromial ligaments have been recognised: an anterolateral band extending from the coracoid process to the posterolateral aspect of the acromion, and an anteromedial band. The thickness of the coracoacromial bands is variable, with the posteromedial band being thicker at the coracoid attachment than at the acromion, whereas the anterolateral band is thicker at the acromion than at the coracoid (Fealy et al., 2005).

Functions:

The coracoacromial ligament has variable function. It (i) supports and counteracts superior displacement of the head of the humerus against the shallow glenoid fossa and laxity of the joint capsule (Smith et al., 1983), (ii) helps to transmit the forces to the axial skeleton (Palastanga et al., 2006), and (iii) prevents superior dislocation of the glenohumeral joint (Moore et al., 2010; Abrahams et al, 2011). The coracoacromial ligament has a role in rotator cuff tears in which cyclic loading of the ligament leads to a significant drop in the peak stress of rotator cuff tear shoulders compared with normal shoulders (Soslowsky et al., 1996). It has been suggested that the coracoacromial ligament provides a stay effect for the acromion and prevents distortion (Putz et al., 1988). It also has a function of static restraint of the glenohumeral joint as complete section of the coracoacromial ligament leads to a significant increase in anterior and inferior translation of the glenohumeral joint (Lee et al., 2001). Following hemiarthroplasty it is agreed that the coracoacromial ligament acts like a restraint against anterosuperior dislocation of the humeral head and should therefore be preserved in surgery to provide joint stability (Hockman et al., 2004). Grafting of the coracoacromial ligament partially or completely in the treatment of massive rotator cuff tears has been tried and has been found to provide a good functional outcome (Bektaser et al., 2010).

Section 4: Biceps brachii and the glenoid labrum

1. Biceps brachii:

Biceps brachii is a long fusiform muscle located in the anterior compartment of the arm: it consists of two heads, short and long. The short head originates from a common origin with coracobrachialis from the tip of the coracoid process of the scapula by a thick flat tendon which runs vertically through the axilla to the arm to meet the long head (Moore et al., 2010; Drake et al., 2005; Gray et al., 1946). The long head arises from the superior glenoid labrum and supraglenoid tubercle at the superior aspect of the glenoid cavity by a long tendon which runs inside the fibrous capsule engulfed in a sheath of synovial membrane (Figures 2.2.1, 2.3.1). It passes superior to the humeral head emerging from the fibrous capsule to run in the bicipital groove (Moore et al., 2010; Gray et al., 1946) deep to the transverse humeral ligament (Moore et al., 2010; Palastanga et al., 2006). Each tendon attaches to a muscle belly which merge close to the elbow joint. It inserts into a rough area on the posterior aspect of the radial tuberosity as well as giving the bicipital aponeurosis from the lateral aspect of the bicipital tendon (Palastanga et al., 2006) which runs obliquely inferomedially to become continuous with the deep fascia of the forearm. A bursa intervenes between the tendon and the radial tuberosity. Superiorly, biceps brachii is covered by deltoid and teres major while inferiorly it is covered by skin and fascia. The musculocutaneous nerve supplies both heads of biceps brachii. The muscle is a powerful supinator of the forearm and flexor of the elbow. The long head prevents superior translation of the humeral head (Moore et al., 2010; Smith et al., 1983; Gray et al., 1946).

Classification of the origin of the long head of biceps tendon:

Vangsness et al. (1994) classified the attachment of the long head of biceps brachii: when it arises approximately equally from the supraglenoid tubercle and the superior glenoid labrum, this was classified as type I, with all fibres attaching posteriorly: this was observed in 22% (n=22) of specimens. In type II fibres mostly attached posteriorly with some anteriorly, this was seen in 33% (n=33) of specimens. In type III there was an equal contribution anteriorly and posteriorly and was seen in 37% (n=37) of specimens. Finally type IV had most fibres attaching anteriorly with a small part posteriorly, this was observed in 8% (n=8) of specimens. On this basis Vangsness et al. (1994) suggest that injury to the long head of biceps could be associated with tears of the glenoid labrum, thus providing an explanation for the detachment of the long head or glenoid labrum correlating with glenohumeral instability. Several authors have subsequently used the Vangsness et al. classification in their studies of the long head of biceps with broadly similar results (Table 2.4.1).

Table 2.4.1: Comparison between different studies using the Vangsness et al. (1994) classification for the attachment of the long head of biceps brachii.

Study	Number of cases	Type I	Type II	Type III	Type IV
Vangsness et al. (1994)	100	22%	33%	37%	8%
Barthel et al. (2003)	36	16.66%	50%	19.44%	13.88%
Clavert et al. (2005)	100	21%	67%	12%	0%
Bain et al. (2012)	19	21%	42%	32%	5%

Bain et al. (2012) also reported that the long head of biceps originates from the supraglenoid tubercle with a contribution of up to one third from the superior glenoid labrum in all specimens. Earlier Pfahler et al. (2003) observed that the long head of biceps arose from the supraglenoid tubercle in 22% (n=7) of specimens, from the superior glenoid labrum in 38% (n=12) and from both the supraglenoid tubercle and superior glenoid labrum in 40% (n=13). However Reis et al. (2009) reported, in a study of foetal shoulders that the long head arose from the posterior glenoid labrum only in 95% (n=19) and from the supraglenoid tubercle in 5% (n=1) of specimens. However, in another foetal study Lapner et al. (2010) observed that the long head of biceps arose from both the glenoid labrum and supraglenoid tubercle in all shoulders. In an evaluation of the anatomical variations in the labral attachment of the long head of biceps brachii it has been suggested that the glenoid cavity can be divided into superior, middle and inferior parts (Paul et al., 2004). The long head arises consistently from the supraglenoid tubercle and glenoid labrum, with the tendon attached to the posterior part of the glenoid labrum in 67% (n=41), dividing the glenoid cavity into superior (22%, n=9), middle (46%, n=19) and inferior (32%, n=13) parts; to the anterior part in 33% (n=20) dividing the glenoid cavity into anterior (27%, n=14) and middle (6%, n=6) parts (Paul et al., 2004). The tendon of the long head of biceps brachii passes posteriorly along the superior edge of the glenoid such that in the majority (92%, n=45) of shoulders the primary composition of the posterior glenoid labrum is the tendon of long head of biceps brachii (Arai et al., 2012).

Although the long head of biceps tendon persistently originates from the supraglenoid tubercle as well as the glenoid labrum, the mode of attachment to the glenoid labrum is variable and can be classified into three types. In type I the long head arises from the supraglenoid tubercle and the posterior margin of the glenoid labrum, observed in 74% (n=37) of specimens; in type II it arises from the supraglenoid tubercle and most of the posterior glenoid with some contribution from the anterior labrum, observed in 20% (n=10) of specimens; and in type III it arises from the supraglenoid tubercle and glenoid labrum with an equal contribution of both anterior and posterior aspects, observed in 6% (n=3) of specimens (Chauhan et al., 2013). It was also noted that the origin of the long head of biceps brachii from the anterior labral margin in 30% (n=15) is only from its upper half, whereas that of the posterior labral margin is from the upper half in 60% (n=30) and the lower half in 40% (n=20) of cases (Chauhan et al., 2013).

Periyasamy et al. (2012) reported that the long head of biceps arises from the supraglenoid tubercle blending with the posterior glenoid labrum in 58% (n=29), with the anterior and posterior glenoid labrum in 39% (n=19) and to the anterior labrum in 3% (n=2) with only a few fibres blending with the posterior glenoid labrum. Between the attachment to the supraglenoid tubercle and the superior glenoid labrum is a small recess which is covered by synovial membrane (Cooper et al., 1992).

Variations in the origin and course of the long head of biceps tendon:

The intra-articular part of the long head of the biceps tendon shows variations, which can be categorized into a series of groups from simple vinculum, cord, pulley type to partial or complete adherence to the fibrous capsule or to the rotator cuff. Kanatli et al. (2011) evaluated these variations and observed that 7.4% (n=50) had variations in the long head of biceps tendon with an associated higher prevalence of labral pathology. It is therefore possible that there is a correlation between variations of the long head of biceps and the occurrence of labral pathology (Kanatli et al., 2011).

Variation of the long head of biceps tendon could be mistaken for a glenoid labrum lesion: Kim et al. (2009a, 2009e) reported one case of the long head of biceps arising from the superior glenoid labrum and tendon of supraspinatus, and another in which the intra-articular course of the tendon was completely adherent to the rotator cuff, which gave rise to shoulder pain. Similarly, Zhang et al. (2014) reported two patients with symptomatic rotator cuff which on MRI and arthroscopy showed the long head of biceps tendon arising from the anterior aspect of the supraspinatus tendon close to its insertion on the greater tuberosity of the humerus.

Egea et al. (2010), Cheema and Singla (2010) and Hammond and Bryant (2013) have all reported the long head of biceps tendon arising from the fibrous joint capsule, which in one case gave rise to shoulder pain (Hammond and Bryant, 2010).

Bifurcated long head of biceps tendon:

Bifurcation of the long head of biceps tendon has been observed incidentally in investigations for glenohumeral joint pathology, being attached to the supraglenoid tubercle and posterosuperior capsulolabral tissue (Enad, 2004).It has also been observed to bifurcate into two bands 1 cm after arising from the supraglenoid tubercle (Kim et al., 2008c) and in the bicipital groove (Borghei and Tehranzadeh, 2010): the latter case was accompanied by pain which was increased by lifting heavy objects. MRI and arthroscopy revealed the long head of biceps bifurcating before it attached to the supraglenoid tubercle and the glenoid labrum by a cord-like structure from the posterosuperior aspect of the tendon complex, which attached superiorly to the superior fibrous capsule and glenoid labrum (Kim et al., 2011). Furthermore, in two cases the long head of biceps origin was Y-shaped with one limb originating just medial to the superior glenoid tubercle and the other from the rotator cable (ligamentum semicircular humeri) (De Giovanni et al., 2008; Wittstein et al., 2012), which is a fibrous band that has an anterior insertion along the anterior fibers of supraspinatus and a posterior insertion along the posterior margin of infraspinatus (Clark and Harryman, 1992). There is also a report of ununited heads of biceps brachii, with the long head inserting into the radial tuberosity and the short head inserting to both the radial tuberosity and bicipital aponeurosis separately (Sawant et al., 2012a).

Three heads of biceps brachii:

A third head of biceps brachii has been reported with the additional head arising from the superomedial part of brachialis on the left side just inferior to the coracobrachialis insertion and was associated with a high origin of brachioradialis: this could contribute to compression on neurovascular bundles (Fating and Salve, 2011). In a study of 50 cadavers a third humeral head of biceps brachii was seen in 6% (n=3) of specimens, being unilateral and in males only: it arose from the anteromedial one third of the humerus and fused with the two other heads to give rise to a common tendon which attached to the radial tuberosity and gave rise to the bicipital aponeurosis (Shalini and Anupama, 2013). Similarly, a third head of biceps brachii was observed to arise from the anteromedial surface of the middle third of the humerus which passed distally to fuse with the long and short heads and insert into the radial tuberosity (Kore et al., 2013). Occasionally a third head of biceps originates from the superomedial aspect of brachialis which then merges and inserts into the bicipital aponeurosis (Gray et al., 1946).

Absence of the long head of biceps tendon:

Absence of the long head of biceps tendon has been reported. In one case the tendon was a cord-like structure deep to the synovium extending from the bicipital groove to the superior glenoid labrum, but was not attached to the muscle belly (Gaskin et al., 2007). In another case, associated with recurrent shoulder dislocations, a hypoplastic long head of biceps tendon, which blended with the fibrous capsule distally and the posterior glenoid labrum posteriorly, was observed: the bicipital glenoid labrum complex did not exist (Gaskin et al., 2007). In a patient with shoulder pain, diagnosed as a rotator cuff tear, MRI and arthroscopy revealed that the long head of biceps tendon was congenitally absent on both sides and was associated with a shallow bicipital groove (Koplas et al., 2009). In a similar case the shoulder was diagnosed as a SLAP lesion; however MRI and arthroscopy revealed a congenital absence of the tendon of the long head of biceps brachii (Ede et al., 2006).

Functions of the long head of biceps tendon:

The precise functions of the long head of biceps tendon are still unclear. Its role was assessed by analysing the effect of simulating the long head of biceps on translation of the humeral head: the study suggested that the tendon stabilizes the glenohumeral joint anteriorly and posteriorly when the arm is rotated internally and externally respectively (Pagnani et al., 1996). Further study has been carried out in order to identify a clinical test that could help in the diagnosis of lesions of the long head of biceps. An applied tensile force has been suggested with the highest tension being in passive joint extension with internal rotation, combined with extension at the elbow and pronation of the forearm; this also means that the long head of biceps tendon provides stability to the glenohumeral joint (Gramstand et al., 2010). Suture anchor tenodesis provides more joint stability and fewer complications than tenotomy in long head of biceps lesions associated with tears in the rotator cuff : this points to the function of providing stability to the glenohumeral joint (Koh et al., 2010).

2. Glenoid labrum:

The glenoid fossa of the scapula is rounded and deepened slightly but effectively by a fibrocartilaginous rim, the glenoid labrum (Snell, 1995; Drake et al., 2005; Palastanga et al., 2006; Sinnatamby, 2006) which has a width of about 4 mm (De Maeseneer et al., 2000) (Figures 2.2.1, 2.3.1). In 1892, it was known as the glenoid ligament (Schafer and Thane, 1892). It is situated within the fibrous capsule of the glenohumeral joint extending the articular surface as well as increasing the security of the articulation (Robinson, 1922). The ring-like labrum is triangular in cross section, with a free central margin and its base attached circumferentially to the margin of the glenoid fossa, forming a depth of about 4 mm (Smith et al., 1983; Palastanga et al., 2006). Many of the fibres attaching to the glenoid margin are short and run obliquely from the internal to external aspects of the glenoid ridge (Robinson, 1922). Vesalius (1543) described the glenoid labrum as a cartilage which works as a ligament augmenting the socket of the scapula and increasing the glenoid fossa concavity therefore decreasing the chance of joint dislocation. He added that the glenoid labrum surrounds the glenoid fossa and does not attach to the scapula or the humeral head, but is only like ligaments which embrace the glenohumeral joint. Its lateral surface is thick becoming thinner towards the centre of the fossa, being triangular in shape with the base (outer side) facing the internal circumference of the glenohumeral joint, while the inner surface interfaces with the glenoid cavity and the superior side facing the humeral head. However, Sager et al. (2009) emphasize that the glenoid labrum does not encircle the whole glenoid and has a variable size, structure, shape and mode of attachment. The attachment of the glenoid labrum posteriorly to the glenoid bone is weaker compared to the inferior aspect and is believed to be due to the posterior sublabral recess.

De Maeseneer et al. (2000) state that the glenoid labrum has common, but variable, variations in shape and mode of attachment to the underlying bone, adding that its cross sectional shape is usually rounded or triangular but the appearance of the anterior part can be triangular, undersized, blunt-tipped or crescentic.

The glenoid labrum provides a site for attachment of the superior, middle and inferior glenohumeral ligaments. The lateral margin of the superior region is considered to be part of the origin of the long head of biceps tendon, while the inferior part provides part of the origin of the long head of triceps. The posterior and superior aspects of the lateral surface of the glenoid labrum provide attachment for the fibrous capsule, while the internal surface is in direct contact with the humeral head and is lined by the synovial membrane (Drake et al., 2005; Palastanga et al., 2006). An internal circumferential labral ridge 4 mm central to the glenoid margin has been reported: this is because the interface of the glenoid labrum and the underlying articular surface of the glenohumeral joint is less prominent at the 2 o'clock position because of the loose attachment of the glenoid labrum (Bain et al., 2012). The synovial membrane is attached to the articular margins and lines the fibrous capsule (Drake et al., 2005). The circumferential attachment of the glenoid labrum is deficient in certain areas resulting in protrusion of the synovial membrane through the gaps (Williams, 1995). The superior region of the glenoid labrum is not well attached to the subjacent glenoid bone, thus its inner edge may protrude into the joint giving a meniscal appearance similar to the knee (Palastanga et al., 2006). Embryologically, Fealy et al. (2000) reported that by week 13 both the anterior and posterior glenoid labrum merge together; after 22 weeks, surprisingly, the anterosuperior glenoid labrum is noted to be detached from the glenoid rim while biceps is attached to the superior labrum. A meta-analysis revealed that the superior and anterosuperior parts of the glenoid labrum are loosely attached to the glenoid process, macroscopically similar to the menisci of the knee and morphologically different to the inferior attachment. The anterosuperior glenoid labrum is triangular in cross section and gives attachment to the middle and/or inferior glenohumeral ligaments, while in contrast the inferior glenoid labrum is rounded and firmly attached to the underlying glenoid (Cooper et al., 1992).

An MRI arthrogram study of asymptomatic male shoulders showed the shape of the glenoid labrum to be variable anteriorly and posteriorly. being triangular anteriorly in 64% (n=69) and posteriorly in 47% (n=51), rounded anteriorly in 17% (n=18) and posteriorly in 33% (n=37), flat anteriorly in 2% (n=2) and posteriorly in 17% (n=18), cleaved in 11% (n=12), and notched labrum in 3% (n=3), as well as being absent anteriorly and posteriorly in 2% (n=2) each (Park et al., 2000). The correlation between MRI and the anatomy of the glenoid labrum demonstrated that grossly the glenoid labrum is variable in both size and shape, being attached firmly to the glenoid rim and hyaline cartilage in 80% (n=8) of shoulders and unattached anteriorly and superiorly in 20% (n=2). MRI-anatomic correlations demonstrate that the morphology of the glenoid labrum is triangular anteriorly and posteriorly in 50% (n=25) of specimens, crescent-shaped in 14% (n=7), rounded in 14% (n=7), flat in 8% (n=4) and cleaved-shaped in 2% (n=1), and absent posteriorly in 6% (n=3) (Figure 2.4.1) (Longo et al., 1996).

In a study using double contrast CT arthrograms (epinephrine and distrizoate sodium meglumine) on shoulders with instability problems ranging from subluxation to recurrent dislocation, the glenoid labrum was described as being variable in size and shape. In three shoulders the normal anterior part of the glenoid labrum was cleaved, notched or redundant. The study also revealed that any change in the usual appearance of the glenoid labrum may not be a labral tear (McNiesh and Callaghan, 1987). Both the anterior and posterior aspects of the glenoid labrum are described as being symmetrical and continuous with the articular surface of the shoulder joint. The posterior labrum is rounded, while the anterior is either rounded or triangular (Haynor and Shuman, 1984; Rafii et al., 1986).

The elastic modulus and stiffness of the glenoid labrum were evaluated in 6 shoulders: the superior labrum had constant thickness, while the anterosuperior and posterosuperior labrum had variable thickness but were morphologically similar; the anteroinferior and posteroinferior labrum was found to be more cartilaginous; and the inferior labrum was thinner and flatter. Differences in thickness and size between sections of the same glenoid labrum and, interestingly, between the dominant and non-dominant limb were observed. The stiffness and elasticity are significantly different between the superior and inferior aspects of the glenoid labrum, but are similar when comparing all superior or all inferior glenoid labra (Carey et al., 2000). There is an intimate relationship between the glenoid labrum and fibrous capsule such that any change in geometry or mechanical properties of the glenoid labrum could lead to glenohumeral joint pathology. Drury et al. (2010) applied an anterior force at different degrees of external rotation and abduction and found that radial thickness and the tensile modulus of the glenoid labrum varied, for instance the peak strains of a thinning glenoid labrum at the axillary region increase at 60^0 external rotation which explains the aetiology of thinning of the glenoid labrum with age (Drury et al., 2010). Hata et al. (1992) reported that there is no significant correlation between the size of the glenoid labrum and the underlying glenoid bone, adding that if one region of the glenoid labrum is large other regions tend to be similar. It was also noticed that the anterior and inferior aspects of the glenoid labrum are the largest suggesting that they could contribute to glenohumeral joint stability. Prodromos et al. (1990) stated, in their analysis, that the consistency of the glenoid labrum is firm and rubbery. They also noted that the glenoid labrum was variable in shape and size according to age, for example in shoulders of individuals in their fifth decade at the time of death the glenoid labrum was thin and virtually absent. The glenoid labrum extended to cover the peripheral margin of the articular surface, in a similar way as the menisci of the knee, in the remaining shoulders. It has been emphasized that the glenoid labrum of individuals younger than 30 at the time of death was firmly attached to the glenoid rim, while the anterosuperior region was detached in 23.52% (n=4) over age 36 with the extent of the detachment increasing with age, however the fibrous capsule remained attached in all shoulders. Howell and Galinat (1989) reported that the glenoid labrum is a fibrous structure which effectively increases the depth of the glenoid socket by 9mm superoinferiorly and 5mm anteroposteriorly and shares in the overall circumferential depth by 50%. Tears of the anterior glenoid labrum, such as in Bankart lesions, decreases glenoid socket depth between 2.4 and 5mm anteroposteriorly and could lead to glenohumeral joint instability.

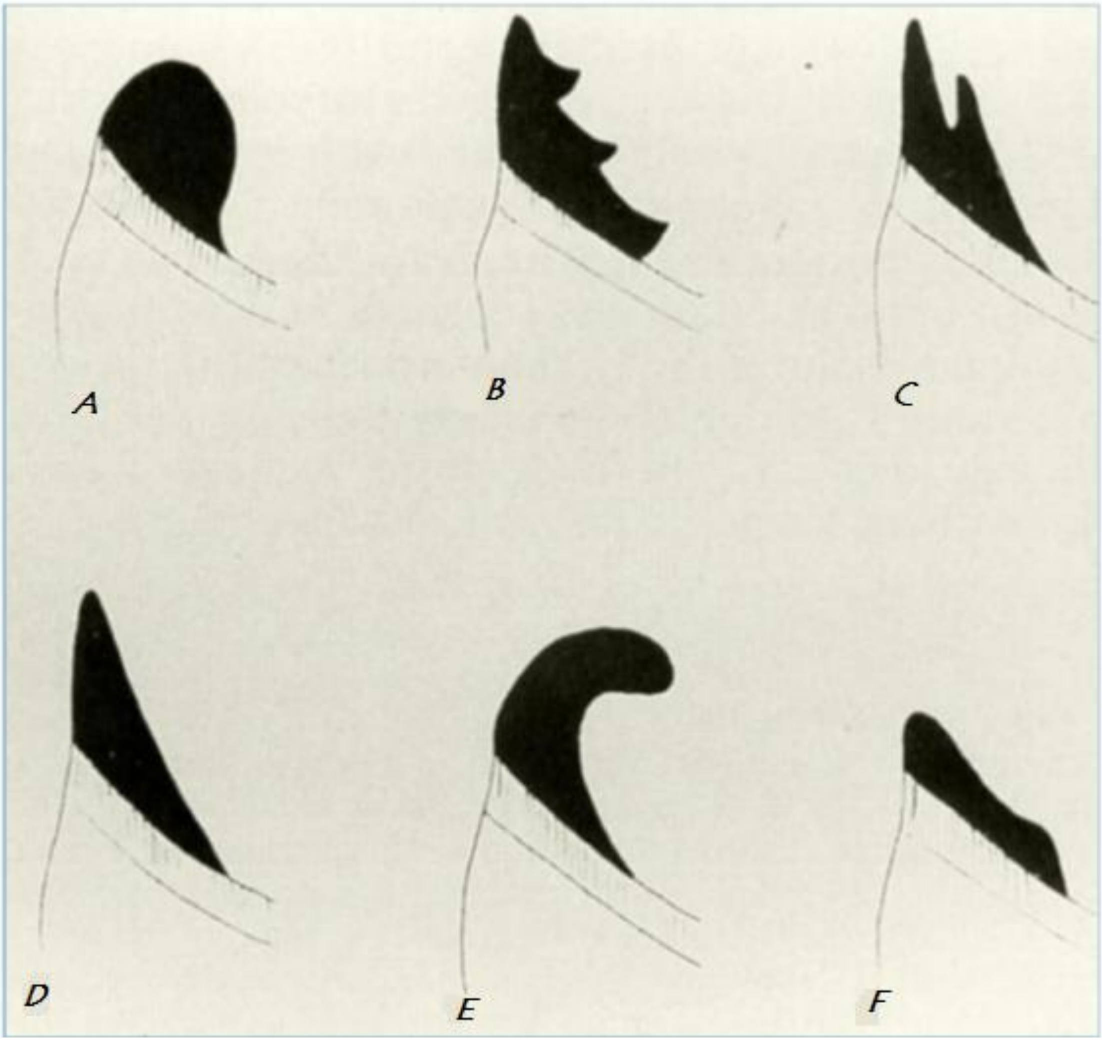


Figure 2.4.1: Labral shapes. A: rounded; B: cleaved; C: notched, D: triangular; E: cresent; F: flat (Longo et al., 1996).

Function of the glenoid labrum:

1. The lateral surface of the superior part of the glenoid labrum provides origin for the long head of biceps tendon and also facilitates in anchoring the capsuloligamentous structures to the glenoid bone (Williams, 1995; Palastanga et al., 2006; Di Giacomo et al., 2008).

2. The inferior aspect of the glenoid labrum provides partial attachment to the long head of triceps as well as the fibrous capsule (Palastanga et al., 2006).

3. It increases the depth of the glenoid cavity, thus protection of the articular surface is accomplished, as well as assisting in lubrication. The labrum also readily yields to the impact and compression of the humeral head against the glenoid cavity without any restriction to free movement of the glenohumeral joint (Vesalius, 1543; Smith et al., 1983; Williams, 1995). Howell and Galinat, (1989) agree that one function of the glenoid labrum is stability of the glenohumeral joint by socket formation. The glenoid fossa with the labrum provides a socket which is deeper superoinferiorly (9mm) than that anteroposteriorly (5mm): the glenoid labrum itself contributes 50% circumferentially which could be an important factor in shoulder stability. Furthermore, a lesion such as Bankart could decrease the depth to 50% in the anterior glenoid labrum: based on this it has been suggested that a loose glenoid labrum could cause glenohumeral instability. Correlation of the glenoid labrum with stability of the glenohumeral joint was investigated by Pouliart and Gagey (2006), who resected the glenoid labrum superiorly, anterosuperiorly, anteroinferiorly and inferiorly leaving the capsuloligamentous structures intact: stability was evaluated before and after resection. The humeral head shifted inferiorly by less than 10 mm in all labral resected shoulders. It was observed that total glenoid labrum debridement led to an increase in translation of the humeral head anteriorly and inferiorly, but did not cause dislocation. The authors therefore proclaim that debridement of any tear of the glenoid labrum, with an intact capsuloligament structure, can be safely performed without creating instability which could lead to joint dislocation.

4. It extends the articular surface (Vesalius, 1543; Robinson, 1922; Smith et al., 1983). The effect of labral progression and bone loss on the articular surface and pressure across the glenohumeral joint have been studied by Greis et al. (2002) using a Tekscan flexible tactile force sensor to determine the contact pressures which were loaded on the

four quadrants of the glenoid labrum. Loss of the anteroinferior aspects of the glenoid labrum lead to a decrease in the contact surface area by 7% to 15% compared to normal shoulders, and an increase in contact pressure by 8% to 20%.

5. The concavity compression stabilization of the glenohumeral joint is enhanced by increasing both the magnitude of the compressive load, which results from dynamic muscle contraction, and glenoid cavity depth. Therefore, the existence of an intact glenoid labrum is important for concavity compression, as well as scapulohumeral balance which also leads to further stabilization of the glenohumeral joint (Lippitt and Masten, 1993). According to Masten and Lippitt (1993), Fehringer et al. (2003) (cited in Smith and Funk, 2010) reported that the magnitude of stability provided by the glenoid labrum through concavity compression is as much as 10% to 20%.

The effect of the glenoid labrum and movement of the arm on stability of the glenohumeral joint has been quantified using the concavity-compression technique. A compression load of 20, 40 and 60N was applied and repeated at 0^0, 30^0, 60^0 and 90^0 abduction with and without the glenoid labrum. The average stability ratio of the glenohumeral joint was greater in adduction than abduction. The highest glenohumeral joint stability ratio was inferiorly (59.8% +/- 7.7%) and the lowest anteriorly (32% +/- 4.4%) with the average glenoid labrum contribution to stability being 10% (Halder et al., 2001).

6. It centralizes the humeral head. This has been studied using a compression load of 30N before and after anteroinferior glenoid labral detachment. Measurements of the humeral head and glenoid labrum position were taken before and after labral detachment. Detachment of the glenoid labrum was associated with translation of the humeral head towards the glenoid labral lesion by an average of 0.74mm. Suture repair to the detached labrum resulted in effective restoration of the humeral head, therefore it

has been concluded that the glenoid labrum plays a role in centralization of the humeral head under modest compressive load conditions in which the ligaments become lax (Fehringer et al., 2003) (cited in Smith and Funk, 2010). The correlation between the extent of the labrum lesion and the frequency of glenohumeral dislocation was evaluated in 93 patients divided into three groups; group I consisted of 35 patients with Bankart/ALPSA (anterior labral periosteal sleeve avulsion) lesion; group II consisted of 32 patients having both Bankart lesion and superior labrum detachment; and group III consisted of 26 patients with a circumferential labral tear, posterior lesion and SLAP lesion. The preoperative dislocation of the glenohumeral joint range was less in group III (P=0.025). There was no significant difference in failure rate among the three groups: however group III did have the lowest failure rate (Kim et al., 2013).

7. It maintains negative intra-articular pressure. Habermeyer et al. (1992) reported that traction of the arm leads to increased negative intra-articular pressure in intact glenoid labrum shoulders, while in glenoid labrum tear cases this is not the case. Therefore, it is considered that the glenoid labrum maintains the negative intra-articular pressure inside the glenoid conferring joint stability, but the magnitude has not been quantified. Moreover, absence of negative pressure inside the joint leads to mechanical movement dysfunction.

8. The mean elastic modulus and yield stress of the glenoid labrum are 22.8 and 2.5 respectively which were noted to be both lower in the anterosuperior aspect of the glenoid labrum compared to the anteroinferior. It was also observed that the tensile material of the glenoid labrum resembles that of the articular cartilage. The elastic modulus of the glenoid labrum is circumferentially variable, consequently it has been speculated that the function of the glenoid labrum is to transfer or counteract forces

resulting from compression of the joint and humeral head translation (Smith et al., 2008).

Blood supply of the glenoid labrum:

No anatomy textbooks mention anything about the vascularity of the glenoid labrum, there are also few papers available. In a study of fresh frozen shoulders it has been suggested that the glenoid labrum is supplied by branches from the suprascapular, circumflex scapular and posterior circumflex humeral arteries, as well as capsular and periosteal branches (Cooper et al., 1992), with the superior and anterosuperior glenoid labrum being less well vascularised than the remainder. No blood vessels were observed arising from the underlying bone to supply the glenoid labrum. The vascular supply of the glenoid bone has also been studied in fresh adult cadavers by injecting coloured latex into the major blood vessels in the axilla (Abrassart et al., 2006). The anterosuperior region has a poor blood supply arising from the suprascapular artery, but has an area which is avascular. The anteroinferior, posteroinferior and posterosuperior regions have a richer blood supply arising from the posterior and anterior circumflex humeral arteries, branches from teres minor and infraspinatus as well as the suprascapular artery. The authors emphasized that there is a circumferential area about 5 mm from the glenoid edge which is completely avascular which could play a role in failure of healing following glenoid fracture (Abrassart et al., 2006).

In a study of dry scapula and cadaveric shoulders Bain et al. (2012) noted that many nutrient foramina were present on the capsular circumferential ridge which supply the glenoid bone. The glenoid labrum was found to be sparsely vascularized without any particular pattern of distribution. Nevertheless, the vascularity has been suggested to decrease with increasing age (Prodromos et al., 1990).

Anatomical variations of the glenoid labrum:

The glenoid labrum, in particular the anterosuperior aspect, is considered to be the most inconsistent in shape with a number of variations, such as sublabral foramen, sublabral recess, Buford complex and discoid labrum, being reported in the literature.

Variation of the anterosuperior part of the glenoid labrum was evaluated in patients who underwent shoulder arthroscopy: three distinct variations were observed in 13.4% (n=73) of patients, these being (1) a sublabral foramen (3.3%, n=18), (2) a sublabral foramen associated with a cord-like middle glenohumeral ligament (8.6%, n=47), and (3) an absence of the anterosuperior aspect of the glenoid labrum associated with a cord-like middle glenohumeral ligament (1.5%, n=8) (Rao et al., 2003). The presence of any of these variations was positively associated with fraying of the anterosuperior part of the glenoid labrum, an abnormal superior glenohumeral ligament and an increase in passive internal rotation of the arm at 90^0 abduction at the shoulder joint (Rao et al., 2003). Elsewhere it has been reported that the glenoid labrum between 10 - 12 o'clock was attached to the apex of the glenoid rim, while in other positions the articular cartilage did not extend to the glenoid edge because the glenoid labrum had a bony foundation and was covered by the glenoid edge. The superior glenoid labrum in cross-section had a concave free articular margin, a loose interface with the articular surface, was relatively mobile and did not increase the depth of the glenoid cavity. In contrast the remainder of the glenoid labrum in cross-section had a rounded convex surface and a well adherent interface with the articular hyaline cartilage (Bain et al., 2012). Most of the shoulder joints were associated with changes in glenoid labrum morphology or the origin of the long head of biceps. The superior and anterosuperior aspects of the glenoid labrum showed a wide range of morphological changes, while in contrast the posterior and inferior aspects were relatively consistent (Barthel et al., 2003).

The posterior glenoid labrum insertion has been classified into 4 types: type I, the posterior glenoid labrum is completely attached to the glenoid with a direct interface with the hyaline cartilage, present in 60% (n=52) of shoulders; type II, the superior part of the posterior glenoid labrum is medially inserted (i.e. attached to the posterior part of the glenoid rim without direct interface to the hyaline cartilage, present in 20% (n=17); type III, the superior and medial parts of the posterior glenoid labrum are medially inserted, present in 15% (n=13); and type IV, is a medial insertion of the whole aspect of the posterior glenoid labrum, present in 5% (n=4) (Nourissat et al., 2014). Variations of the posterosuperior glenoid labrum and rotator cuff appear to be correlated with the type of sport undertaken as demonstrated in a study of 51 patients, lesions of the posterosuperior glenoid labrum were noted in 22 patients (fraying in 95.4% (n=21), cracking in 18.1% (n=4), detachment of the superior and posterior aspects in 40.9% (n=9)) (Dewan et al., 2012). Variations of the anteroinferior part of the glenohumeral capsulolabrum have also been observed with the joint put into the position of anterior shoulder dislocation (abduction, external rotation) then serially sectioned in the transverse place from proximal to distal. Three shoulders were histologically prepared while the remainder were frozen and then sectioned. Two variations were observed: in type I the anteroinferior capsulolabrum originated mainly from the glenoid labrum with some contribution from the glenoid neck, observed in 80% (n=8); in type II the labrum only arose from the glenoid neck, observed in 20% (n=2) (Eberly et al., 2002).

Correlation between glenoid labrum variations and other anatomical variations and pathologies:

An MRI study of 88 shoulders revealed a correlation between glenoid morphology and variation of the anterosuperior glenoid labrum, which was classified into 4 categories: no variation, diminutive (minute) labrum, sublabral foramen and Buford complex. Two groups were identified according to the shape of the glenoid. In group I the glenoid was notched, 13 shoulders (15%) of which 3 (23%) had a Buford complex, 2 (15%) a sublabral foramen, 4 (31%) a diminutive labrum; while in group II the glenoid labrum was ovoid, 75 shoulders (85%) of which 3 (4%) had a Buford complex, 8 (11%) a sublabral foramen, and 7 (9%) a diminutive labrum. A significant association (P=0.001) between glenoid morphology and variations of the anterosuperior glenoid labrum was observed (Shortt et al., 2009). The glenoid labrum was also investigated in 191 shoulders and three morphological labral types identified: type I, a triangular labrum present in 44% (n=85); type II, a meniscoid labrum present in 38% (n=72); and type III, a bumper labrum observed in 18% (n=34). In 49 (26%) shoulders the superior glenoid tubercle was covered by articular cartilage (mobile labrum) with no evidence of any pathology; which should not be considered as a type II SLAP lesion. Furthermore, the glenoid labrum was classified as type I in 42.85% (n=21), type II in 26.53% (n=13) and type III in 30.61% (n=15). There was no significant correlation between the type of glenoid labrum and the presence of articular cartilage over the supraglenoid tubercle of the scapula (Davidson et al., 2004). In another study to evaluate the relationship between the variation of the glenoid labrum and its pathology, a sublabral foramen was seen in 18.5% (n=20) and a Buford complex in 6.5% (n=7) of shoulders. In these shoulders it was noted that the incidence of SLAP lesions was significantly higher than in the remainder (Ilahi et al., 2002).

Discoid shape:

A discoid glenoid labrum has been reported in a patient who complained of spontaneous induced right shoulder pain associated with weakness in supraspinatus: the diagnosis was a spinoglenoid cyst with discoid glenoid labrum. The cyst was surgically removed and the glenoid labrum found to cover all of the articular hyaline cartilage apart from a

1 cm diameter central circular area: trimming of the free margin of the glenoid labrum and debridement were performed and at two years follow up full joint function was restored (Rhee et al., 2006).

Sublabral foramen:

A sublabral foramen is defined as a complete thickness separation of the glenoid labrum from the bone and usually occurs in the anterosuperior aspect the glenoid (Bain et al., 2012). A sublabral foramen is asymptomatic clinically and considered to be a variant of the anterosuperior capsulolabral complex. It can be seen during arthroscopy or MRI of the shoulder and might be misdiagnosed as a glenoid labrum tear. In an anatomical study a sublabral foramen was predominantly found in older individuals: therefore it is suggested that its presence is an age related development, being trauma induced if present in younger individuals (Schulz et al., 2002). Barthel et al. (2003) observed sublabral foramen and describe it as a physiological variant. In two hundred shoulder arthroscopies a sublabral foramen was seen in 12% (n=24) below the anterosuperior glenoid labrum (Williams et al., 1994). An analysis revealed that the shape of the glenoid fossa was teardrop-shaped (pear-shaped) in 90% (n=29) and elongated oval in 10% (n=3). A sublabral foramen was found in 16% (n=5) of shoulders with a mean of length of 7mm. Associated lesions such as fissures of the glenoid labrum were observed in 19% (n=6) of shoulders and glenoid labrum detachment in 10% (n=3) (Pfahler et al., 2003). Bain et al. (2012) revealed a sublabral foramen in 26% (n=5) of specimens examined. Using MRI arthrography a sublabral foramen was observed in only 7% (n=2) of the sample (Park et al., 2000); however in a similar study using both MR and CT arthrography a Buford complex was seen in 2% (n=1) (Waldt et al., 2006). Smith et al. (2008) reported that sublabral foramen in 10% (n=1). Recently an arthroscopic study found sublabral foramen in 15% (n=16) of the sample (Wilson et al., 2013). Is the presence of a sublabral foramen associated with joint instability? Two age and side-matched groups, each consisting of 10 individuals with and without sublabral foramina, were assessed to compare the anterior and posterior maximum density of the glenoid using computed tomography osteoabsorptiometry. There was no change in glenoid density between the two groups suggesting that the presence of a sublabral foramen is not correlated with joint instability (Schulz et al., 2004).

Buford complex:

Buford complex incidence is variable in the literature and is defined as absence of the anterosuperior aspect of the glenoid labrum with a cord-like middle glenohumeral ligament arising from the superior glenoid labrum (Williams et al., 1994; De Maeseneer et al., 2000). In an arthroscopic study Williams et al. (1994) reported a Buford complex in 1.5% (n=3) of patients. Park et al. (2000) found a Buford complex in 2% (n=2), and similar Waldt et al. (2006) observed it in 2% (n=1) of shoulders using both MR and CT arthrography.

However, the pathophysiology and association of the Buford complex to glenohumeral joint instability or the susceptibility of a glenoid labrum tear is still unclear. In a case study by Del Rey et al. (2009) a 29 year old male patient complained of shoulder instability: MRI revealed an insufficient anterior glenoid labrum. Intra-articular arthroscopy was performed and showed an absence of the anterior glenoid labrum as well as the middle glenohumeral ligament being cord-like and therefore diagnosed as a Buford complex. Reattachment of the middle glenohumeral ligament to the glenoid rim after abrasion was undertaken with glenoid labrum reconstruction. After two years the patient fully recovered with no signs of instability (Del Rey et al., 2009). In a study of sports related patients, variations of the posterosuperior glenoid labrum and rotator cuff were found to be correlated to the type of sport: a Buford complex was noted to be present in 9.8% (n=5) of patients. The associated lesions were of the anterosuperior aspect of the glenoid labrum in 43.13% (n=22), a rotator cuff tear in 49% (n=25), a SLAP lesion type II in 25.49% (n=13) and Bankart lesion in 21.56% (n=5) (Dewan et al., 2012). The correlation of a Buford complex and SLAP lesions has been retrospectively demonstrated in 235 shoulders: a Buford complex lesion was found in 6 cases (2.5%), 5 of which also had a SLAP lesion and needed surgical intervention. In the remaining 229 cases, a SLAP lesion was found in 17.5% (n=40): it was concluded that there is a significant association between a Buford complex and SLAP lesions (Bents and Skeete, 2005). A Buford complex was accidentally found in a 16 year old boy with a SLAP type VI (Brue et al., 2008).

Sublabral (recess) cleft:

The glenoid labrum recess was first described by Cooper et al. (1992) and is defined as a separation between the glenoid labrum and articular surface with an intact base which usually occurs in the superior aspect of the glenoid labrum at 12 o'clock. It can be differentiated from a sublabral foramen (the complete separation of the glenoid labrum in the anterosuperior aspect locates at 2 o'clock) and the synovial (labral) recess (separation between the long head of biceps tendon and underlying superior glenoid labrum and lined by synovial membrane), but the differentiation between normal variational anatomy of the glenoid labrum and the pathology remains difficult (De Maeseneer et al., 2000; Bain et al., 2012). An intimate relationship between the attachment of the long head of biceps and the superior aspect of the glenoid labrum is appreciated when the relationship of the superior aspect of the glenoid labrum and superior part of the glenoid bone has shown anatomical variation "the superior sublabral recess". Attachment of the labral bicipital complex to the glenoid has been classified into: type (I), firm attachment to the glenoid; type (II), a small recess can be seen between the glenoid labrum and the glenoid; and type (III), a deep recess is present between the glenoid labrum and the glenoid sufficient to allow the insertion of a probe. The sublabral sulcus can be continuous with the sublabral foramen, with differentiation radiologically between a type III sublabral recess and a SLAP lesion type II considered to be very difficult (De Maeseneer et al., 2000; Harzmann et al., 2003).

The exact cause and process in the creation of a sublabral recess remains unclear; however the incidence of a sublabral sulcus increases with age. It is suggested that a high frequency of repetitive movement of the glenohumeral joint, such as in overhead sports, together with age and the type of insertion of the long head of biceps tendon to the superior aspect of the glenoid labrum predispose the development of a sublabral recess. It has also been found that a deeper sublabral recess is associated with the posterior insertion type of the long head of biceps to the glenoid labrum and does not exist with the anterior insertion type to the glenoid labrum (Harzmann et al., 2013). Lapner et al. (2010) investigated the gross anatomy and histology of the superior glenoid labrum in foetuses ranging from 11 to 20 weeks and found it to arise directly from the superior cartilaginous analage with an intimate attachment between the superior glenoid cartilage and superior aspect of the glenoid labrum: in other words the sublabral recess does not exist.

Bain et al. (2012) reported a sublabral cleft in 89% (n=17) of shoulders studied using MRI arthrography. However, Park et al. (2000) reported a sublabral recess in only 33% (n=36), while Sager et al. (2009) observed an anterosuperior sublabral recess in 50% (n=18) of shoulders.

Controversially, in a cadaveric meta-analysis using non-enhanced MR imaging and MR arthrography and histological sections, a sublabral recess was found in 73% (n=19), being deeper than 2mm in 39% (n=10). There was no significant association between the type of the sublabral recess and age or sex. Histologically, a synovial lining of the sublabral recess was observed with no signs of fibrosis being detected. Based on these observations it has been suggested that a sublabral recess is a normal anatomic structure rather than a traumatic induced lesion: MRI arthrography is a better choice to determine the sublabral recess (Smith et al., 1996).

Other sublabral recesses:

In an arthroscopic and CT study a posterior labral recess was found in 18.9% (n=24) of shoulders, predominately in females in the inferior quadrant of the posterior glenoid labrum (between 7 and 8 o'clock). An associated lesion, such as a posterior glenoid labrum tear, was seen in 9.4% (n=12), predominately males. It was concluded that a posterior labral recess exists and is considered to be a normal variant and should not be misdiagnosed as a glenoid labrum tear. To differentiate between a posterior labral recess and posterior labral tear by CT scan is first to determine if there is any history of trauma, secondly the incidence of a posterior labral recess is higher than a posterior glenoid labrum tear, thirdly if the labral abnormality is found in the posterior glenoid labrum between 7 – 8 o'clock, and fourthly if it has shallow depth, because the mean depth of a posterior labral tear is significantly larger than that of a labral cleft; therefore it is most likely to be a posterior labral recess rather than a glenoid labrum tear: arthroscopy is the diagnosis of choice (Lee et al., 2009).

Recently, in an MRI arthrography meta-analysis correlated by arthroscopy Tuite et al. (2013) reported that a sublabral recess was seen in 68% (n=60) of patients, with 7% being within the posteroinferior aspect of the glenoid labrum and 61% within the posterosuperior aspect. From the MRI, 55-83% of sublabral recesses were 1 mm in depth and 0-37% were 2 – 3 mm in depth. The sublabral recess was seen commonly in the anterior, anteroinferior and posterosuperior aspects of the glenoid labrum. The sublabral recess in the anteroinferior aspect of the glenoid labrum could be particularly misleading because it has similar MRI characteristics to partial labral detachment tears. It was added that there is no significant association between the existence of a sublabral recess and age or gender. An evaluation of variations of the superior labrum and labrobicipital complex using MR arthrography, multi-slice CT arthrography and anatomical dissection has been undertaken using the Smith et al. (1996) classification of the mode of attachment of the superior labrum to the glenoid rim (see page 42). According to anatomical dissection only 74% (n=32) of shoulders revealed a sublabral recess. The attachment of the superior labrum was observed as type (I) in 23% (n=10), type II in 19% (n=8), type III in 23% (n=10) and type IV in 33% (n=14). The observations of MRI showed a sublabral recess in 26 shoulders (60%) with 6 being missed; therefore the sensitivity, specificity, accuracy and negative and positive predictive values of MRI in detecting sublabral recesses are 81%, 100%, 86%, 65% and 100% respectively. The results from CT arthrography showed a sublabral recess in 27 shoulders (63%) with 5 being missed; therefore the sensitivity, specificity, accuracy and negative and positive predictive values of CT arthrography in detection of sublabral recess are 84%, 100%, 88%, 69% and 100% respectively. Therefore, the accuracy of detection of the sublabral recess by using MRI and CT arthrography is 59% and 81% respectively with no significant difference between them. Furthermore, the superior labrum was divided into three segments; anterior (between 10 - 11 o'clock), central (between 11 - 1 o'clock) and posterior (between 1 - 2 o'clock): the sublabral recess was located anterior (13%, n=4), central (19%, n=6), posterior (6%, n=2), anterior and central (38%, n=12), central and posterior (3%, n=1) and in all segments (22%, n=7) (Waldt et al., 2006).

Section 5: Stability, instability and dislocation of the glenohumeral joint.

1. Stability

The glenohumeral joint is unstable due to the disproportionate nature of the articular surfaces, as well as the laxity of the joint capsule. Several factors contribute to stabilization of the glenohumeral joint (Palastanga et al., 2006; Sinnatamby, 2006; Abrahams et al., 2011). Firstly, the glenoid labrum deepens the glenoid fossa effectively extending its articular surface, therefore playing an important role in shoulder stabilization. In cases of fracture of the glenoid or glenoid labrum tears, patients may suffer shoulder dislocation (Palastanga et al., 2006). Secondly, the glenohumeral joint is surrounded by the rotator cuff muscles (Ellis, 2006; Lumley et al., 1995), which encircle the shoulder anteriorly, superiorly and posteriorly (Lumley et al., 1995; Faiz and Moffat, 2006). They are significant in stabilization of the glenohumeral joint because their insertions are close to the joint capsule: furthermore their tendons blend with the joint capsule forming a musculotendinous sleeve strengthening the joint capsule (Figure 2.5.1) (Smith et al., 1983; Palastanga et al., 2006; Sinnatamby, 2006). They act to stabilize the glenohumeral joint without any alteration in mobility (Drake et al., 2005). This musculotendinous collar also prevents impingement of the lax fibrous capsule and its synovial membrane between the articular surfaces during movement (Palastanga et al., 2006). However, as there is no musculotendinous cuff associated with the inferior aspect of the joint the joint capsule is weak and the joint relatively unstable (Smith et al., 1983; Palastanga et al., 2006). Nevertheless during abduction both teres major and the long head of triceps come into contact with the joint capsule providing some stability (Palastanga et al., 2006). As well as the rotator cuff, all muscles that pass from the shoulder girdle to the humerus provide some stability to the glenohumeral joint, for example the long head of biceps brachii, the long head of triceps in addition to pectoralis major, latissimus dorsi and teres major (Palastanga et al., 2006; Ellis, 2006) (Figure 2.5.2). The long head of biceps brachii passes intracapsularly superior to the head of the humerus, counteracting superior movement of the humeral head against the glenoid fossa thereby assisting in preventing superior dislocation of the joint (Smith et al., 1983; Ellis, 2006). The long head of triceps supports the joint capsule when the arm is abducted (Palastanga et al., 2006). Thirdly, the stability of the glenohumeral joint is enhanced by the coracoacromial arch superiorly (Lumley et al., 1995; Drake et al., 2005). It has been suggested that the coracohumeral and glenohumeral ligaments also contribute to stability of the glenohumeral joint (Sinnatamby 2006; Abrahams et al., 2011).

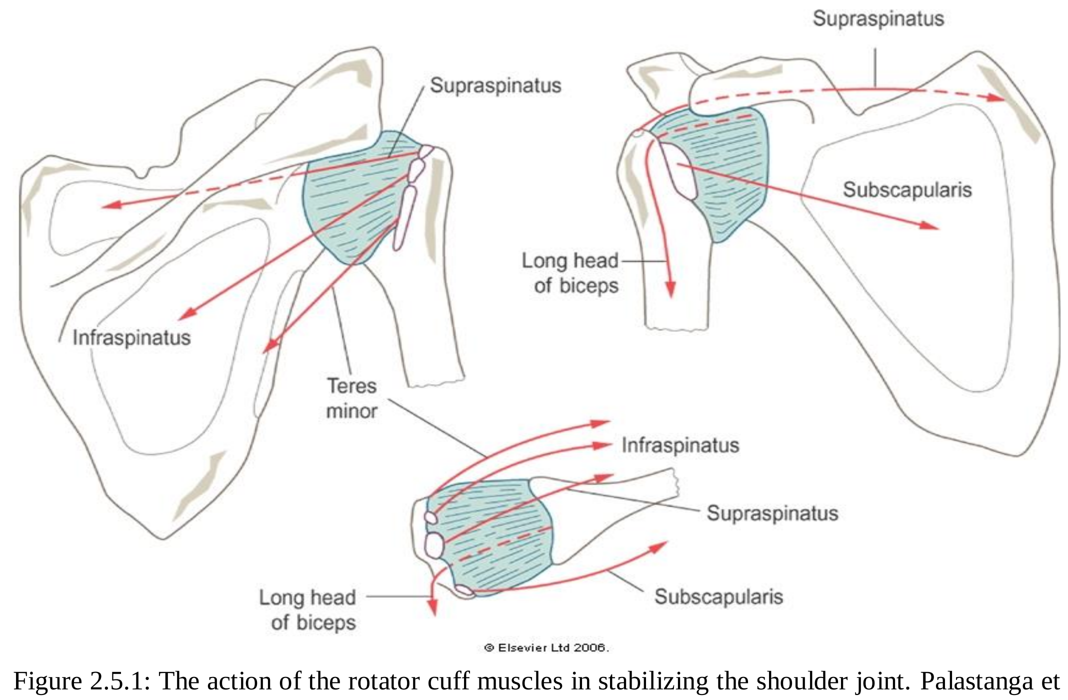


Figure 2.5.1: The action of the rotator cuff muscles in stabilizing the shoulder joint. Palastanga et al. (2006) Anatomy and Human Movement, 5th edition.

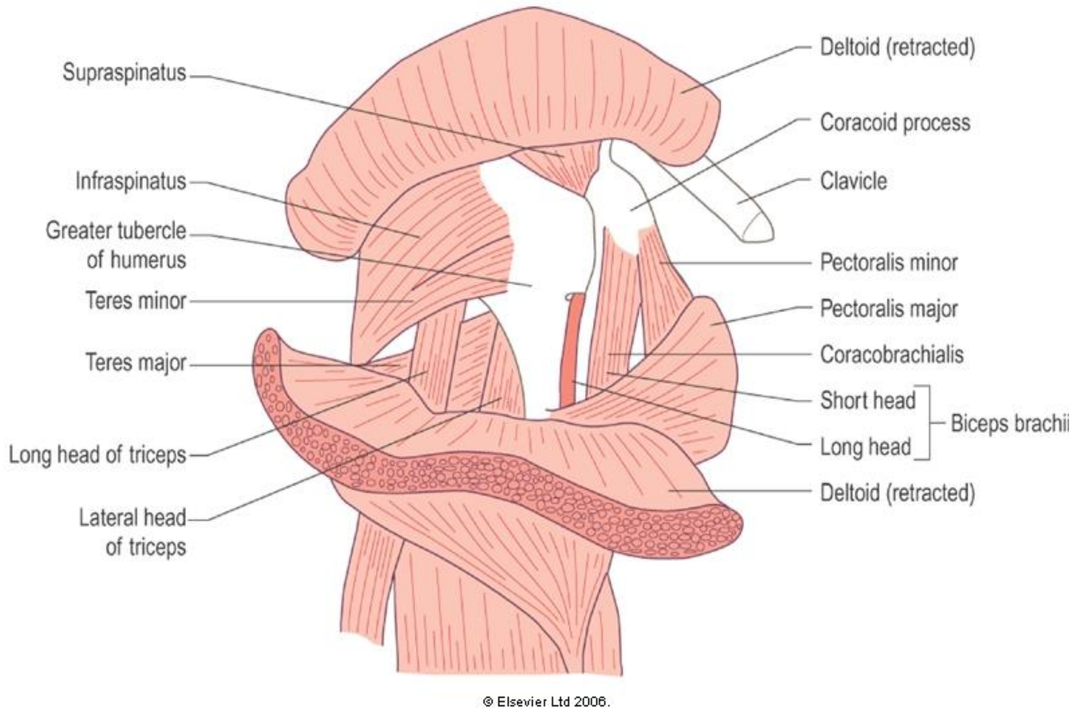


Figure 2.5.2: Lateral view of muscles involved in stabilizing the shoulder joint. Palastanga et al. (2006) Anatomy and Human Movement, 5th edition.

2. Instability

Definition:

The complexity of the glenohumeral joint allows a great range of mobility which increases the risk of dislocation. Stability of the joint is essentially maintained by active and passive mechanisms. The passive mechanism relies on the glenoid labrum, adhesion and cohesion of the articular surfaces, fibrous joint capsule, the glenohumeral ligaments and the size and shape of the glenoid fossa, whereas the active mechanism includes the rotator cuff muscles and tendon of the long head of biceps: therefore, any pathology of these mechanisms will lead to instability (Beltran and Suhardja, 2007). Instability constitutes a broad spectrum of glenohumeral joint disorders ranging from microinstability due to laxity and subluxation through to dislocation: it is therefore important to identify the cause of the instability. Instability is an abnormal or symptomatic movement of the humeral head with respect to the glenoid fossa. Laxity is a passive movement of the joint commonly seen in overhead athletes without the creation of symptomatic instability (VandenBerghe et al., 2005). Subluxation is a partial slip of the humeral head out of the glenoid fossa, while in dislocation the humeral head moves completely out of the glenoid fossa. Karahan et al. (2012) highlighted that the pathogenesis of instability not only includes an anatomical lesion but also a combination of pathologies associated with the joint.

Classification:

There are several classifications of instability. Silliman and Hawkins (1993) based their classification on a clinical basis according to:

(1) The degree of instability: dislocation and subluxation; dislocation of the glenohumeral joint is a complete separation between the humeral head and the glenoid which requires active reduction, subluxation is a partial separation between the humeral head and the glenoid (Blum et al., 2006; Walch, 1996).

(2) The direction of instability: anterior, posterior and multidirectional instability.

Anterior instability is more common than posterior and multidirectional with an incidence of traumatic anterior instability of the glenohumeral joint being 1.7% in the general population. A good clinical history and radiological investigation are effective in evaluating the direction of the instability. Anterior glenohumeral dislocation constitutes 95% of all types of dislocations (Blum et al. 2006, Dumont et al., 2011).

(3) Chronology: acute, recurrent or chronic.

Acute glenohumeral dislocation is diagnosed on the first day and is considered to be chronic if it is observed after three weeks. Recurrent instability is repeated subluxation or dislocation: it is seen predominately in young athletic males (Blum et al. 2006, Row, 1987, Walch et al, 1996). Recurrent glenohumeral dislocation occurs after a first time dislocation in 29.44% of the population, being more frequent between 21 and 30 years (Kralinger et al., 2002).

(4) Aetiology: traumatic (generally involuntary) or atraumatic (generally voluntary)

On the basis of pathogenesis, the aetiology is characterized to help in its clinical determination (surgical vs. conservative treatment). TUBS expresses patients with Traumatic instability, with Unilateral involvement, commonly involving a Bankart lesion and often needing Surgery. AMBRI refers to Atraumatic instability, which might be Multidirectional, commonly Bilateral and treated by either Rehabilitation or an Inferior capsular shift. In addition there is a third type AIOS which refers to Acquired Instability from Overstress and usually needs Surgery (Beltran and Suhardja 2007).

Pathogenesis:

Instability of the glenohumeral joint occurs if any of the active or passive mechanisms have been affected. Most of the causative factors have been emphasized in detail in previous sections, but will be mentioned here for clarification: for example (1) pathology of the glenoid labrum such as Bankart, Perthes or ALPSA lesions, (2) glenoid cavity: congenital or traumatic induced version insufficiency, (3) glenohumeral ligaments and fibrous capsule: laxity and deformity of the joint capsule, (4) humeral head: congenital or traumatic induced version insufficiency, (5) long head of biceps tendon: SLAP, and (6) rotator cuff muscle tears could cause glenohumeral joint instability (Karahan et al., 2012).

The association between the glenoid labrum and instability:

The association between the anterior glenoid labrum and anterior glenohumeral stability was examined by Yamamoto et al. (2009). A defect of 6 mm in the width of the anterior glenoid labrum was created following which the stability ratio of the glenohumeral joint significantly decreased suggesting that the anterior glenoid labrum plays a role in anterior glenohumeral stability and reinsertion of any anterior glenoid labrum tear should be performed. The effect of detachment of the superior glenoid labrum on the stability of the biceps anchor was evaluated by Gates et al. (2009) with the creation of superior, anterior and posterior labral tears: the displacement of the biceps anchor had a remarkable effect on stability. Sixteen cadaveric shoulders with posterior instability were investigated and divided into a labral lesion group and a capsular lesion group: significant instability of the joint was apparent being inferiorly with posterior capsular lesions, posteriorly in posterior glenoid labrum lesions, and posteroinferior in accompanied lesions (Wellmann et al., 2011). Moreover, traumatic shoulders with a lesion in the anterior, inferior and posterior glenoid labrum resulted in the greatest glenohumeral instability. All patients had 2+ or more anteroinferior instability and bilateral (anteroposteroinferior) instability in 89.5%. Patients all underwent arthroscopic 270^0 suture anchors of the detached glenoid labrum. The postoperative outcome was significantly effective, with complete joint stability being achieved in 85% of patients (Mazzocca et al., 2011). Creation of an anteroposterior labral lesion type II associated with anterior capsular laxity resulted anterior glenohumeral joint instability after the repair (Mihata et al., 2008). Changing the glenoid labrum thickness and modulus of elasticity has the ability to change the strain on the fibrous capsule and glenoid labrum; it has been observed that high peak strains in the glenoid labrum are more frequent in thin or degenerative glenoid labra, which confirmed the concept that tissue degeneration could be the cause of glenoid labrum pathology (Drury et al., 2010).

Ahmad et al. (2003) reported that instability of the glenohumeral joint was still observed even after repair of Bankart lesions in patients with labral deficiency and anteromedial capsule redundancy with an incidence of 49% (n=38): therefore, the medial capsule imbrication technique and buttress of the glenoid, which is known as barrel stitch, was performed: stability was achieved in 92% of patients. In a study by Kim et al. (2010a) of patients with their first glenohumeral dislocation and those with recurrent dislocation it was noted that those with first time dislocations lesions of the glenoid labrum were noted as follows: Bankart lesion (24.24%, n=8), free anterior glenoid labrum periosteal sleeve avulsion (ALPSA) (27.27%, n=9), bony Bankart lesion (12.12%, n=4) and adhesive ALPSA (3.03%, n=1). In contrast, in those with recurrent dislocations, observed lesions of the glenoid labrum were: Bankart lesion (61.26%, n=68), free ALPSA (9.09%, n=11), bony Bankart lesion (11.71%, n=13), adhesive ALPSA (14.41%, n=16) and disruption lesion of the articular glenoid (0.9%, n=1). Lesions of the anteroinferior glenoid labrum were observed in first time dislocation to be 66.6% (n=22) and in recurrent dislocations 98.1% (n=109): the authors also point out that patients with recurrent dislocation had a significantly higher proportion of inverted pear-shaped glenoids, being 13.51% (n=15) (Kim et al., 2010a). In a later study (Kim et al., 2013) the correlation between the extent of the labral lesion and the frequency of glenohumeral dislocation was evaluated in patients divided into three groups: group I consisted of 35 patients with a Bankart/ALPSA (anterior labral periosteal sleeve avulsion) lesion defined as detachment of the glenoid labrum between 2 - 6 o'clock; group II consisted of 32 patients with both a Bankart lesion and superior labral detachment defined as detachment of the glenoid labrum between 10 - 2 o'clock; and group III consisted of 26 patients with a circumferential labral tear defined as a combination of anterior labral lesion (2 - 6 o'clock), posterior lesion (6 - 10 o'clock) and SLAP lesion. Interestingly, the preoperative dislocation of the glenohumeral joint range was significantly less in group III (P=0.025). There was no significant difference in failure rates among the three groups; however group III did have the lowest rate of failure (Kim et al., 2013).

The correlation between labral fixation site and glenohumeral translation was assessed by Black et al. (1999) in which glenohumeral translation was recorded after repair of the superior and middle anterior parts of a glenoid labrum lesion and after repair of the superior, middle and inferior part of an anterior glenoid labrum lesion. A three site repair of the anterior glenoid labrum lesion resulted in a significant decrease in humeral translation and increased stability to the joint (Black et al., 1999). A 33 year old male complained of left shoulder pain after sustaining an anteroinferior dislocation after a fall on his outstretched left hand. MRI and arthroscopy revealed an anterior labroligamentous periosteal sleeve avulsion of the superior part of the glenoid labrum (ALPSA). Two staples were used to reinsert the glenoid labrum and other tissues in place and a capsulolabral tissue repair was done in a lateralised position. After 15 months the patient was back to normal with full abduction, a 10^0 limitation of extension and no glenohumeral dislocation (Atay et al., 2002).

A simulated superior labral anteroposterior lesion type II was produced in cadaveric shoulders and the glenohumeral range of motion as well as translation, evaluated. It was noted that external rotation increased significantly by 2.7^0 associated with a small increase in anterior (0.9 mm) and posterior (0.9 mm) joint translation to the level that it did not affect the kinematics of passive movement of the joint (Youm et al., 2008).

Management of instability:

Anterior instability:

Due to the high incidence of recurrence, operative management for instability is more frequent especially in younger individuals compared to non-operative treatment. Different types and causes of instability require different operative procedures, either arthroscopically or by open surgery (Wambacher et al., 2006).

Arthroscopic management:

Arthroscopic stabilization techniques have improved and have now become comparable to open repair surgery. The Hammock technique has been developed to address both bands of the inferior glenohumeral ligament and has shown satisfactory outcomes (Fabing and Andreson, 2007). Based on a cadaveric study, 10 mm anteroinferior arthroscopic suture plication was applied and an effective significant reduction was observed in anterior translation and external rotation (Alberta et al., 2006). On the basis of another cadaveric study, Bohnsack et al. (2009) declared that arthroscopic anatomic reconstruction of a Bankart lesion with suture anchors without over-constraint of the anteroinferior aspect of the fibrous capsule provides sufficient stabilization. Supporting this arthroscopic bio-absorbable sutures of an L-shaped tear of the inferior glenohumeral ligament in a paediatric patient resulted in a successful outcome (Nho et al., 2009). Kim et al. (2008b) introduced a new technique using a single suture anchor with two non-absorbable braided sutures to repair the glenoid labrum and fibrous capsule separately. It increased the strength of the labral repair and also allowed for a reduction in fibrous capsule volume to restore stability. There are several types of anchored suture, with Milano et al. (2010) investigating the difference between metal and biodegradable suture anchors with a follow up of two years: no difference was found. Lino and Belangero (2006) introduced a triple combined procedure which included labral repair, reduction of the fibrous capsule volume and suture of the rotator cuff interval. When performed on patients with a mean follow up of 32.4 months stability was observed in all shoulders with a marked functional improvement.

Open surgery:

An open Bankart procedure with absorbable suture anchors performed on patients with a mean of follow up of 90 months resulted in glenohumeral joint stability in 83% (n=15) (Magnusson et al., 2006). Recurrent anterior glenohumeral joint dislocation can be effectively reduced using the Putti Platt technique with an incidence of postoperative recurrence of 1% (n=1) (Pritsch et al., 1983).

Comparison between different techniques:

Comparing arthroscopic transglenoid sutures and open capsulolabral repairs in patients with a follow up of 5 years, Hubbell et al. (2004) reported that dislocation and instability rates were 17% (n=5) and 60% (n=18) respectively in the arthroscopic group with no limitation of movement, while in the open capsulolabral group no dislocation or instability occurred, however there was a mean limitation of external rotation of 18^0 in 45% (n=9) of patients. In a study comparing three operative groups, patients with the open Bankart technique, patients with an arthroscopic Bankart procedure and patients with a bone-block technique, Wambacher et al. (2006) reported a Rowe score function result classification of 91%, 80.6% and 95.4% respectively with a complication rate of 6.4%, 16.3% and 4.4% respectively. It was concluded that the bone-block procedure provided the best outcome in stability. In a comparison between arthroscopic capsulolabral reconstruction using arthroscopic transglenoid fixation and suture anchor fixation Kim et al. (2008a) reported that recurrent instability occurred in 26.9% (n=7) patients who underwent transglenoid fixation and in only 10% (n=2) in patients who had the suture anchored technique. There was a significant difference between both groups, with reconstruction by suture anchor being the more effective and reliable treatment option. In chronic instability open reconstruction of the anterior glenohumeral capsulolabral structures with a tibialis anterior allograft was used to recreate the anterior glenoid labrum, middle glenohumeral ligament and the anterior band of the inferior glenohumeral ligament (Braun et al., 2011): 70% (n=14) showed good results with no further instability observed.

Management of instability associated with glenoid bone defect and fracture:

Anterior recurrent instability associated with massive bone loss is not common. Surgical reconstruction using intra-articular tricortical iliac crest bony allograft in order to re-build the shape of the glenoid resulted in no recurrence with all patients returning to their sport (Warner et al., 2006). Reconstruction of the glenoid surface by J-shaped bicortical iliac crest bone implanted in the defect region at the glenoid neck also resulted in no further instability in any of the patients (Auffarth et al., 2011). Moroder et al. (2012) added that reconstruction by a J-shaped bone allograft leads to very good glenoid shape. According to Martetschlager et al. (2013) in recurrent instability with glenoid bone loss of greater than 20 – 25% bone reconstruction is recommended. A cannulated titanium screw system was used in fixation in patients with a glenoid bone fracture extending at least 21% of the glenoid length. Fractures healed completely and stability was achieved in 80% (n=8) of patients, while in the other 20% (n=2) dislocation and glenohumeral joint impingement were complications (Tauber et al., 2008). In cases of anterior glenoid labrum lesion associated with glenoid cartilage flap, the glenoid labrum has been reconstructed by a suture anchor using a mattress stitch to the cartilage, which was applied peripherally in order to stabilize the flap. A secure outcome and complete recovery was achieved without chondral damage at 1 year follow up (Page and Bhatia, 2010). In contrast, Pagnani (2008) reported that bone defects of the humeral head or the glenoid fossa did not appear to lead to a significant decrease in stability recurrence. They declared that bone-block or allograft is not necessary to restore stability: in addition there is a high complication rate when associated with open capsular repair. Mologne et al. (2007) also declared that stability can be achieved by arthroscopic stabilization of recurrent instability associated with a glenoid bone deficiency of 25% without bony allograft.

Posterior and posteroinferior (multidirectional) instability:

Provencher et al. (2005) undertook arthroscopic stabilization of posterior instability using suture anchors or suture capsulolabral plication or both, reporting it to be effective in 78.8% (n=26). Radkowski et al. (2008) state that the arthroscopic posterior capsulolabral technique enhances stability, range of motion, joint strength and function in throwing athletes. According to Nho et al. (2010) a simple stitch is recommended for plication of the posterior capsule for posterior instability because it has a less traumatic effect on the capsulolabral tissue. In a comparison of shoulders with posterior instability treated either by thermal capsular shrinkage, labral re-attachment or capsulorrhaphy and a mean of follow up of 50 months, recurrent instability was observed in 21% (n=4) being predominantly after thermal capsular shrinkage. Therefore, Engelsma and Willems (2010) concluded that stabilization with labral re-attachment or capsulorrhaphy gives better results. Even in recurrent posterior instability arthroscopic capsulolabral reconstruction was effective and reliable with 90% (n=180) of patients returning to sports (Bradley et al., 2013). In cases of multidirectional instability arthroscopic capsulolabroplasty a successful outcome was achieved in all shoulders (Kim et al., 2004).

3. Dislocation of the glenohumeral joints:

Dislocation of the shoulder is common (Palastanga et al., 2006) either by direct or indirect trauma (Moore et al., 2010), in comparison to other joints because it has sacrificed stability over mobility. Inferior dislocation is more frequent, anterior and posterior dislocations are less frequent: superior dislocation is unlikely to occur (Palastanga et al., 2006; Sinnatamby, 2006) because of the presence of the coracoacromial arch, rotator cuff muscles (Moore et al., 2010) and long head of biceps brachii (Drake et al., 2005). Dislocation of the shoulder can damage the joint capsule and glenoid labrum, with recurrent dislocations being more likely to occur (Sinnatamby, 2006). Glenoid labral tears are more frequent in athletes or in those who have experienced shoulder instability. A sudden contraction of biceps brachii or powerful subluxation of the shoulder joint tears the glenoid labrum, which usually occurs in the anterosuperior aspect (Moore et al., 2010). However, glenoid labral tears also occur in the anterior aspect of the glenoid labrum (Faiz and Moffat, 2006); with anterior dislocation of the shoulder joint leading to posterior tears of the glenoid labrum (Rogers, 1992).

Anterior dislocation:

Anterior dislocation is a common occurrence in adults (Palastanga et al., 2006), mainly in athletes (Moore et al., 2010), occurring during excessive extension and lateral rotation of the arm (Moore et al., 2010). During dislocation the humeral head passes between the inferior glenohumeral ligament and the long head of triceps to lie inferior to the coracoid process (Palastanga et al., 2006): others report the humeral head to be displaced inferoanteriorly (Faiz and Moffat 2006; Moore et al., 2010) creating a bulge at the clavipectoral groove; at the same time the contour of the shoulder joint disappears (Palastanga et al., 2006).

As the glenohumeral joint is the most mobile joint in the body, it therefore has a tendency to dislocate with a peak incidence between 20 and 60 years of age. Anterior dislocation accounts for the majority of glenohumeral dislocations. Traumatic anterior dislocation is commonly associated with intra-articular lesions which might be aggravated by recurrence: it can be associated with fractures, tears of the rotator cuff and neurovascular injuries. One of the most common side effects is instability (Bankart, 1923, Ufberg et al., 2004, Chechik et al., 2011, Gutierrez et al., 2012). Bilateral traumatic anterior glenohumeral joint dislocation is rare affecting predominantly males with a mean of age 33.5 years, while in females the average age is 57 years: it may be associated with fractures of the greater tuberosity (Dlimi et al., 2012, Ballesteros et al., 2013).

The recurrence rate of anterior glenohumeral dislocation after initial dislocation in young athletes is between 54% and 92% (Wheeler et al., 1989, Bottoni et al., 2002, Te Slaa et al., 2003, Jakobsen et al., 2007). According to Milgrom et al. (2014) re-dislocation occurs in 60% (n=31) of after first time dislocation. The anterior apprehension (spine apprehension) test, which predicts the risk of dislocation, was positive in 79% of patients and negative in 53% patients. Auffarth et al. (2013) reported that recurrence after first time traumatic anterior glenohumeral dislocation is common, being occasionally associated with loss of glenoid bone, and can reach 41% in first time dislocation and 86% in recurrent dislocation. According to Saito et al. (2005) recurrent anterior glenohumeral dislocation was associated with a deficient glenoid rim in 8% to 95% of individuals: the deficit was more frequent in the anterior glenoid rim between 2:30 and 4:20.

Causes:

There are several causes that can lead to anterior dislocation of the glenohumeral joint. According to Bankart (1923) falling on an abducted arm in which the head of the humerus is impacted against the acromion process and then pushed to the weakest part of the capsule between subscapularis and the long head of triceps. Non-traumatic causes have been reported by Chahal et al. (2010), such as general capsular laxity and an increase in external rotation of the glenohumeral joint.

Bilateral anterior dislocation may be caused by trauma in 50% of cases, muscle contraction in 37% as an outcome of seizures of different origin such as epilepsy or hypoglycaemia, and by electric shock. Non-traumatic causes constitute 13% of cases (Ballesteros et al., 2013). Chin-ups exercise was found to place the humeral head in a situation that make it susceptible to bilateral anterior dislocation (Felderman et al., 2009).

Many factors can aggravate redislocation but one of the most important causes of recurrent anterior glenohumeral dislocation is an undiagnosed glenoid bone lesion (Auffarth et al., 2013). Bankart (1923) declared that abnormal capsular laxity and weakness of the surrounding muscles, or falling either directly on the posterior aspect of the glenohumeral joint or on the elbow joint, which causes direct impaction of the humeral head, can lead to dislocation. Tears in the fibrous capsule and the glenoid labrum cause a permanent defect in the joint allowing the humeral head to recurrently dislocate anteriorly.

Signs and symptoms:

Pain and limitation of movement with the limb slightly abducted and externally rotated. Asymmetrical appearance can be seen with loss of the lateral contour of the shoulder and a flattened appearance. On examination, the humeral head may be palpable (Ballesteros et al., 2013).

Types:

Acute anterior glenohumeral dislocation:

Chronic (irreducible, persistent) anterior glenohumeral dislocation is not common: it can be due to interposition of the torn subscapularis tendon between the humeral head and glenoid fossa (Connolly et al., 2008).

Diagnosis:

Radiology can be useful in diagnosis revealing the humeral head in the subcoracoid space (Gudena et al., 2011; Dlimi et al., 2012; Ballesteros et al., 2013). According to Auffarth et al. (2013) as there is a high incidence of associated bony loss with traumatic dislocation a CT scan of the glenohumeral joint after each primary dislocation is suggested to facilitate early proper treatment and avoid further complications.

Associated lesions:

The associated lesions after first time traumatic joint dislocation are many with variable incidence. According to Bankart (1923), Dlimi et al. (2012) and Auffarth et al. (2013) the associated lesions in first time traumatic dislocation are glenoid rim fracture (41% - 86%), Hill-Sachs lesion (40%, n=8) and fracture of the greater tuberosity (15%, n=3). Gutierrez et al. (2012) reported that Bankart lesion was seen in all patients with first time traumatic anterior dislocation. Comparing recurrent anterior dislocations and first time anterior dislocation posterior Bankart and SLAP lesions were more frequent in recurrent anterior dislocation being 47% (n=24) and 28% (n=14), and 24% (n=12) and 12% (n=6) respectively. Moreover, Hill-Sachs lesions of different size and Bankart lesion were seen in all patients and SLAP lesions type I and III were found in 7.40% (n=2) (Bottoni et al., 2002). After twenty five years follow up of first time glenohumeral dislocation of 227 patients (aged 12 – 40 years) Hovelius and Saeboe (2009) reported that normal shoulders were found in 44% (n=113) and arthropathy in 54% (n=144): recurrent dislocation occurred in 39% (n=100) of shoulders. The authors declared that arthropathy was influenced by factors such as age, recurrence, type of sports and alcohol abuse.

Lesions including the fibrous capsule have also been reported. McMahon et al. (2013) reported that two distinctive capsulolabral lesions were found, these being a tear of the anteroinferior glenoid labrum between 2 - 6 o’clock in 50% (n=11) of cases, while in the remaining 50% (n=11) the anterior aspect of the fibrous capsule was loose and patulous. The anterior and inferior compression forces were significantly decreased after the third dislocation (McMahon et al., 2013). According to Bankart (1923) an anterior detachment of the fibrous capsule from the glenoid labrum can also be observed.

Fractures have also been observed in 47% of cases by Ballesteros et al. (2013): the most common being of the greater tuberosity constituting 78% of the lesions, being bilateral in 53% and unilateral in 47%. The remaining 22% consisted of glenoid rim fracture, humeral head and neck fractures.

A Baker lesion was also observed in 93.5% (n=71) of patients (Jakobsen et al., 2007), while Te Slaa et al. (2003) reported it in all shoulders with the following accompanying lesions, SLAP in 3.22% (n=1), rotator cuff tears in 22.58% (n=7) and Hill-Sachs lesions in 93.54% (n=22).

Treatment:

Close reduction:

Several studies reported different techniques for close reduction of the dislocated glenohumeral joint (Chechik et al., 2011), with the modified Milch technique being recommended by Singh et al. (2012) in all cases of acute anterior dislocation without associated fracture because it was safe, effective, had less morbidity and was well tolerated. Ballesteros et al. (2013), however state that close reduction using Kocher's technique has shown adequate recovery with no signs of dislocation being detected at two years follow up. Close reduction can usually be accomplished in any anterior glenohumeral dislocation combined by avulsion fracture of the greater tuberosity of the humerus (Ilahi, 1998).

In cases of dislocation with an associated greater tuberosity fracture close reduction followed by immobilization in adduction and internal rotation for three weeks followed by physiotherapy has shown good results (Dlimi et al., 2012). Immobilization in abduction and external rotation has been effective and shown fewer recurrent dislocations (3.8%, n=1) in comparison to immobilization in adduction and internal rotation where the incidence of recurrence was 33.3% (n=17) (Heidari et al., 2014). Furthermore, immobilization of the glenohumeral joint after acute traumatic anterior dislocation in 30^0 external rotation appears to allow a similar adjustment of the glenoid labrum regardless of the duration of immobilization (Scheibel et al., 2009). In contrast, according to Liu et al. (2014), immobilization of the upper limb in external rotation does not reduce the rate of recurrence after primary anterior glenohumeral joint dislocation or improve the quality of life compared to immobilization of the upper limb in internal rotation. Vavken et al. (2014) state that there is no clear evidence that immobilization in external rotation after first time traumatic dislocation decreases the incidence of recurrence compared to internal rotation. Failure to achieve close reduction following dislocation can be caused by interposition of soft or osseous tissue, therefore open reduction is required (Guha and Jago, 2004, Connolly et al., 2008, Gudena et al., 2011).

Operative treatment:

Arthroscopic stabilization is potentially the most common even after first time dislocation using biodegradable bone anchors, especially in young patients (Bottoni et al., 2002; Chechik et al., 2011; Malhotra et al., 2012). Treatment of anterior glenohumeral dislocation should be based not only on the number of recurrences, but also on the best outcome results: the primary stabilization option (arthroscopic suture anchor repair) should be the first line in the high risk group, i.e. individuals younger than 25 years old (Boone and Arciero, 2010). In non-athletic patients over 30 years of age Kim et al. (2009c, d) reported no significant difference between the transglenoid and suture anchored techniques: however, the transglenoid technique can be an alternative if suture anchors were not present. Not only is the range of movement and incidence of redislocation an advantage of arthroscopy, Edmonds et al. (2003) also reported that proprioception would be affected.

Comparing the outcome of primary arthroscopic stabilization with close reduction after first time traumatic glenohumeral dislocation in an active military population with a mean of follow up of 6 years Shih et al. (2011) reported that redislocation occurred in

92% (n=23) within 18 months in close reduction, whereas only 5.1% (n=2) of the operative group suffered from redislocation within 12 months of follow up: there was also a significant difference in the range of movement between the two groups. Bottoni et al. (2002) reported that arthroscopic stabilization after traumatic first time dislocation had an 11.1% (n=1) recurrence in comparison to non-operative management (75%, n=9). According to Jakobsen et al. (2007), using the Oxford score, conservative treatment of acute glenohumeral joint dislocation had a 74% (n=29) unsatisfactory outcome compared to 72% (n=27) good satisfaction after surgical arthroscopy. In recurrent anterior dislocation non-operative treatment does not show any positive results while arthroscopic treatment after acute dislocation had glenohumeral stability in 78% (n=7), therefore it is recommended as the operation of choice in young patients following first time anterior glenohumeral dislocation (et al., 1989).

In cases of recurrent anterior dislocation due to bony glenoid erosion Weng et al. (2009) suggested that open reconstruction and a bone graft technique showed viable outcomes, whereas Auffarth et al. (2008) reported that anatomical glenoid reconstruction via a J-bone graft give great results.

On the other hand, Te Slaa et al. (2003) reported that after 5years post glenohumeral arthroscopy there was no correlation between Bankart lesions and glenohumeral joint instability. It is therefore unlikely that glenohumeral arthroscopy reduces the incidence of recurrent glenohumeral dislocation after first time dislocation in young individuals.

Posterior dislocation:

Posterior dislocation is uncommon: the underlying factors are the glenoid fossa faces anterolaterally and therefore counteracts any direct posterior force. In addition, infraspinatus and teres minor play a significant role in supporting the joint capsule posteriorly. Although posterior dislocation of the shoulder joint can occur if a posterior thrust along the long axis of the humerus is applied during abduction and medial rotation of the arm (Palastanga et al., 2006). It has been pointed out that posterior dislocation could damage the axillary nerve located just beneath the shoulder joint capsule, which is manifested by a loss of skin sensation over the central part of deltoid, as well as paralysis of deltoid (Sinnatamby, 2006; Moore et al., 2010).

The incidence of posterior glenohumeral dislocation constitutes 4% of total dislocations and is more common in males, but the reasons are unknown. It can be easily missed therefore it should be seriously considered: a careful history and clinical assessment are very important, especially if there is associated pain in the posterior aspect of the shoulder accompanied by loss of external rotation (Norman and Harrison, 1963; Nobel, 1969; Eyre-Brook, 1972; Hawkins, 1987; Cicak, 2004; Robinson and Aderinto, 2005; Dlimi et al., 2013). It can be bilateral if caused by an epileptic attack (Norman and Harrison, 1963; Gopal-Krishnan and Shelton, 1972). Mclaughin (1952) described failure to diagnose posterior dislocation as the most serious complication, with one of the most common reasons being that a routine anteroposterior radiograph often looks normal (Nobel, 1969).

Causes:

The increase in the prevalence of diabetes mellitus and alcohol consumption, as well as drug dependency, has increased the number of dislocations that occur during seizures as a sign of hypoglycaemia and drug withdrawal: seizures enhance dislocation due to a high trauma load (Gopal-Krishnan and Shelton, 1972; Eyre-Brook, 1972; Hepburn et al., 1989; Steinmann et al., 2003), or after electric shock or falling on an outstretched hand (Cicak, 2004). Severe direct trauma to the adducted and internally rotated arm or a direct blow to the anterior aspect of the glenohumeral joint, as well as seizures, are considered to be the commonest causes according to O'Connor and Jacknow (1956), with an incidence of 56.25% and 43.75% respectively. In a cadaveric study Oversen and Sojbjerg (1986b) reported that posterior glenohumeral dislocation was seen in all specimens after complete rupture of the posterior fibrous capsule as well as teres minor associated with incomplete rupture of the infraspinatus tendon in the vast majority of shoulders. In another cadaveric study Oversen and Nielson (1986a) reported that major injury to the anterior aspect of the glenohumeral fibrous capsule is required to elicit posterior glenohumeral subluxation only. Saupe et al. (2008) reported posterior dislocation caused by electric shock, seizure and trauma to be 2.94% (n=1), 2.94% (n=1) and 94.11% (n=34) respectively. In contrast, Schwartz et al. (1987) (cited in George et al., 2012) found that incision of the whole posterior fibrous capsule could produce posterior subluxation only: posterior dislocation cannot be achieved even if the limb is placed in the provocative position predisposing to posterior dislocation because the anterior fibrous capsule and the glenohumeral ligaments become tense.

Signs and Symptoms:

Pain and loss of movements at the glenohumeral joint, especially during external rotation. On examination, the typical resting position is internal rotation with adduction, described as the Valpeau position. The range of internal rotation is between 10° and 60° with no external rotation possible: there is loss of the glenohumeral contour and the humeral head is in the posterior glenoid rim and can be palpable (O’Connor and Jacknow, 1956; Nobel, 1969; Gopal-Krishnan and Shelton, 1972; Cicak, 2004; George et al., 2012; Dlimi et al., 2013). The coracoid and acromion processes are more prominent (Nobel, 1969). Associated fractures mask these signs and symptoms in 70.5% and can mislead the diagnosis (O'Connor and Jacknow, 1956). Nobel (1969) noted that clinical signs and symptoms can sometimes be absent. For persistent posterior dislocation a stiff and painful shoulder is the most obvious sign and symptom (Norman and Harrison, 1963).

Diagnosis:

A high index of suspicion of dislocation can be achieved after a detailed history and careful examination augmented by radiological techniques (Norman and Harrison, 1963; Robinson and Aderinto, 2005). Radiography can diagnose a posterior dislocation (Gopal-Krishnan and Shelton, 1972; Eyre-Brook, 1972; Cicak, 2004) which is taken in anteroposterior, axillary and lateral scapular views; however the anteroposterior view will only show a flattened appearance of the humeral head, which in itself is not conclusive. The axillary view shows the size of the defect on the anteromedial side of the humeral head, while the lateral scapular view determines the relation between the glenoid fossa and humerus. The radiological finding is that the anterior aspect of the humeral head is inside the joint while the posterior aspect is outside. Alternatively, a CT scan is the most useful tool in diagnosis (Norman and Harrison, 1963; Postacchini and Facchini, 1987; Cicak, 2004; Lin et al., 2013). One of the signs that may be seen in an anteroposterior radiograph is absence of a semilunar shadow between the humeral head and glenoid fossa, thus an axillary view is essential (Nobel, 1969).

Compared to recurrent anterior dislocation recurrent posterior dislocation is hard to diagnose and considered to be critical because the type of surgery is not the same (Eyre-Brook, 1972).

Classification:

Different classifications of posterior glenohumeral joint dislocation have been reported in the literature. According to Cicak (2004) and Eyre-Brook (1972) it can be classified into acute, chronic (persistent, locked, missed and fixed), recurrent and habitual. Based on its aetiology, Gopal-Krishnan and Shelton (1972) classified it as congenital, habitual or traumatic. Based on the degree of the displacement O'Connor and Jacknow (1956) classified it as subluxated, subacromial or subspinous. Traumatic dislocation is an acute dislocation in which the humeral head is completely dissociated from the glenoid fossa: it is commonly seen after trauma. First time post-traumatic dislocation is known as simple dislocation or true fracture dislocation. Simple dislocation is occasionally associated with an anterior osteochondral impression fracture of the humeral head, while a true fracture dislocation is associated with fractures of the humeral tubercles and/or the proximal end of the humerus. It is predominant in males but the reasons are unclear (Gopal-Krishnan and Shelton, 1972; Robinson and Aderinto, 2005). Chronic posterior dislocation is defined as of more than three weeks duration following a missed acute dislocation and is characterized by an impression fracture of the articular surface (Cicak, 2004). It is very uncommon and can remain undiagnosed for long periods (Norman and Harrison, 1963). Habitual posterior dislocation is defined as repeated voluntary glenohumeral joint dislocation due to laxity of the soft tissues and associated ligaments and is commonly seen in adolescents. It is difficult to control: an associated large posterior capsular pouch is observed on arthrograms (Eyre-Brook, 1972). Fracture can be associated with posterior dislocation, therefore Robinson and Aderinto (2005) have classified posterior dislocation into simple dislocation and fracture dislocation (dislocation with fractures of the tuberosities and/or proximal aspect of the humerus).

Associated lesions:

According to Neer (1970) posterior shoulder dislocation can be accompanied by fracture of the articular surface of the humeral head with or without humeral shaft fracture, as well as fractures of the humeral tuberosities which can be classified as a two, three or four part fracture dislocation. Nobel (1969) observed that tears of the glenoid labrum or fibrous capsule were associated with posterior dislocation. In MRI study of patients with an acute first time posterior dislocation Saupe et al. (2008) reported that reverse Hill-Sachs lesions were observed in 86% (n=31), a reverse Bankart lesion in 31% (n=11), posterior capsuloligamentous complex lesion in 58% (n=21), fracture of the posterior glenoid rim in 31% (n=11) and rotator cuff tear in 42% (n=15). Lin et al. (2013) state that a reverse Hill-Sachs lesion is always associated with posterior dislocation and is seen in all patients.

Treatment:

In acute dislocation, reduction under general anaesthesia should be performed: this is achieved by pulling the arm while the assistant is manually pushing the humeral head anteriorly towards the glenoid fossa. After reduction is achieved immobilization of the arm in a sling is mandatory for two and half to three weeks (Nobel, 1969; Gopal-Krishnan and Shelton, 1972). Mclaughin (1952) state that acute dislocation responds well to the treatment while recurrent dislocations require surgical intervention. According to Cicak (2004), the standard management of posterior dislocation relies on several factors, such as the size of the defect, its duration and the age and activity of the individual. For instance, posterior dislocation associated with up to 25% articular surface defect is treated by either close or open reduction. In cases of instability, fixing the subscapularis tendon can be achieved. If the dislocation is associated with a humeral head fracture between 25% and 50% it can be treated by lesser tuberosity transfer, but if it is larger than 50% joint hemiarthroplasty is the preferred option.

Eyre-Brook (1972) emphasized that the best treatment for persistent posterior dislocation is McLaughlin's operation in which an anterior glenohumeral approach is performed with a full thickness incision of the anterior capsule. Reduction of the humeral head can easily be reduced and stability is accomplished by fixing the detached subscapularis tendon into the anterior notch of the humeral head. The advantages are that external rotation can be achieved after release of the contracted anterior structures and the risk of crushing the humeral head against the contracted tissues can be avoided. Gopal-Krishnan and Shelton (1972) mention that stripping the fibrous capsule extensively followed by immobilization of the arm in flexion and abduction for four weeks because the strong inferior capsule contraction is successful. McLaughlin’s operation is not effective in habitual dislocation, in which case the surgery of choice is by a posterior graft attached to the infraspinous fossa with the fibrous capsule placed between the graft and humeral head: no limitation in the ranges of motion were noted (Eyre-Brook 1972). Gopal-Krishnan and Shelton (1972) state that appropriate posterior fibrous capsule and soft tissue repair is the treatment for habitual dislocation.

Inferior dislocation:

Inferior dislocation “luxatio erect humeri” is a rare type constituting about 0.5% of all glenohumeral dislocations, the reason being that it has a specific occurrence mechanism and clinical presentation. During dislocation, the humeral head lies inferior to the glenoid and the humeral shaft is directed superiorly and is internally rotated (Fery and Sommelet, 1987; Yamamoto et al., 2003; Begaz and Mycyk, 2006; Dahmi et al., 2008; Groh et al., 2010; Imerci et al., 2013; Petty et al., 2014). Intuitively inferior dislocation is expected to be more common because of the lack of support from tendons and muscles inferiorly (Faiz and Moffat, 2006; Abrahams et al., 2011). It occurs when a force is applied to the humerus with the arm abducted more than 90^0, extended and laterally rotated. It is often accompanied by tears of the glenoid labrum (Sinnatamby, 2006). In addition, there may also be a greater tubercle avulsion fracture (Moore et al., 2010). Furthermore, damage to the axillary nerve can potentially occur as a consequence of inferior dislocation of the shoulder (Faiz and Moffat, 2006). It can be bilateral “hands up” position and potentially associated with musculoskeletal and neurovascular injuries (Brady et al., 1995; Kumar et al., 2001). It has been observed to be predominantly on the left side and to be 75% (n=6) in males and 25% (n=2) in females with an average age of 40 years (Dahmi et al., 2008).

Causes:

Several factors could cause inferior dislocation, such as direct trauma (Davison and Orwin, 1996; Begaz and Mycyk, 2006; Kumar et al., 2001), falling on the upper limb while in abduction or flexion (Padgham and Walker, 1996; Dahmi et al., 2008; Kumar et al., 2001; Petty et al., 2014), or an hyper-abduction injury to the arm (Mallon et al., 1990; Yamamoto et al., 2003).

Types:

Acute inferior dislocation is not frequent and can be reduced by close reduction (Groh et al., 2010)

Chronic inferior dislocation is known as neglected dislocation and is very rare. It is occasionally associated with lesions and needs surgical intervention (Davison and Orwin, 1996; Dhar et al., 2013).

Signs and symptoms:

Besides the pain and limitation of movement, it has a classical arm position of “hyperabducted” or locked in an upright position of approximately 80^0 with the elbow flexed and the forearm pronated. The humeral head may be palpable inferior to the glenoid fossa (Sarkar et al., 1989; Padgham and Walker, 1996; Begaz and Mycyk, 2006;

Petty et al., 2014). In contrast Sonanis et al. (2002) reported a case with traumatic inferior dislocation without the hyperabduction posture: the arm was in the neutral position.

Diagnosis:

Anteroposterior and axillary view radiographs are effective in diagnosis and show the humeral head inferiorly dislocated with the humeral shaft axis above the horizontal. It can be confused with subglenoid anterior dislocation but the classical position of hyperabduction is only seen in inferior dislocation confirmed by radiography (Begaz and Mycyk, 2006; Dahmi et al., 2008; Dhar et al., 2013).

Associated lesions:

There are several lesions associated with inferior glenohumeral joint dislocation in the literature, such as fracture of the greater tuberosity (80% of cases), fracture of the spine of the scapula (Mellon et al., 1990; Davison and Orwin, 1996; Yamamoto et al., 2003; Begaz and Mycyk, 2006), fracture of the coracoid process, clavicle, acromion, humeral head (Wang et al., 1992), rotator cuff tear (80% of cases), penetration of the skin inferior to pectoralis major, circumferential tear of the fibrous capsule just lateral to the glenoid labrum, axillary nerve injury (60% of cases) (Mallon et al., 1990; Davison and Orwin, 1996; Yamamoto et al., 2003), fracture of the glenoid (Uzela and Laflammeb, 2009), ligamentous tear, labral tear and Hill-Sachs variant lesions on the superolateral region of the joint (Sarkar et al., 1989; Saseendar et al., 2009). Compartment syndrome of the arm is rare but can occur as a consequence of inferior dislocation (Yen et al., 1988). Injuries to the brachial plexus and axillary artery are potential risks (Fery and Sommelet, 1987; Brady et al., 1995; Padgham and Walker, 1996; Plaga et al., 2010).

Treatment:

Close reduction:

Close reduction by overhead traction-countertraction produced under sedation, muscle relaxation and analgesia followed by a Dujarier's bandage for three weeks is very useful in the vast majority of cases with an excellent long term prognosis (Mellon et al., 1990; Padgham and Walker, 1996; Begaz and Mycyk, 2006; Dahmi et al., 2008; Groh et al., 2010; Petty et al., 2014). According to Nho et al. (2006), Saseendar et al. (2009) reported that neurological lesions have less chance to occur and better results can be achieved by using a two-step manoeuvre which aims to convert the humeral head from the inferior dislocation to an anterior dislocation which can then be reduced inside the glenoid fossa.

Operative treatment:

Operative treatment is typically indicated in cases of chronic dislocation associated with or without lesions, or in acute dislocation associated with displaced humeral head fracture or in patients with recurrent dislocation (Davison and Orwin, 1996; Uzela and Laflammeb, 2009; Groh et al., 2010).

Intra-thoracic fracture dislocation of the humeral head:

Intra-thoracic dislocation is defined as a fracture dislocation of the humeral head into the thoracic or abdominal cavity and is considered to be extremely rare. The mechanism of injury is caused by a high-energy trauma, such as a fall from a high place onto an abducted arm or in road traffic accidents (Kocer et al., 2007; Maroney and Devinney, 2009; Daffner et al., 2010; Hawkes et al., 2014). Patients usually complain of shoulder pain, limitation of movement, chest pain and difficulty in breathing (Daffner et al., 2010; Du Plessis et al., 2012; Wiesler et al., 2004). Radiographs and a CT scan are useful in diagnosis as they reveal fracture dislocation of the humeral head which lies within the thoracic cavity devoid of any soft tissue attachment (Brogdon et al., 1995; Daffner et al., 2010; Hawkes et al., 2014). There are a number of associated lesions, such hemothorax, pneumothorax, pulmonary contusion, fractures of the coracoid process, ribs and scapula, subcutaneous emphysema and crepitation, vascular injury to the subclavian artery and axillary nerve palsy (Kocer et al., 2007; Daffner et al., 2010; Abellan et al., 2010; Hawkes et al., 2014). Surgical treatment by hemiarthoplasty is the choice after treatment of the associated lesions followed by physiotherapy (Wiesler et al., 2004; Kocer et al., 2007; Daffner et al., 2010).

Superior dislocation:

Superior dislocation is rarer than inferior dislocation because the shoulder is supported by the coracoacromial arch consisting of the coracoid process anteriorly, the acromion process posteriorly and the coracoacromial ligament between, together with the assistance of the long head of biceps brachii. Despite this the coracoacromial arch is not considered to be a part of the shoulder joint, however it plays an important role in preventing superior dislocation (Palastanga et al., 2006; Abrahams et al., 2011). In addition, any superior force applied to the humerus leads to fracture of the clavicle or the humerus and not the coracoacromial arch (Sinnatamby, 2006). To the author’s knowledge there are very few cases reported in the literature. Downey et al. (1983) reported three cases (2 males, 1 female) and De Laat et al. (1997) only one case. The causes of dislocation were falling on the posterior aspect of an extended limb, or induced by direct repetitive superior and anterior applied forces on the humerus to bedridden elderly in helping them to sit up. The patient suffers from pain and limitation of movement especially abduction. One individual with bilateral dislocation was observed to have hyperextended arms. Anteroposterior and axillary view radiographs demonstrate the humeral head anterior to the coracoid and acromion processes. Avulsion fracture of the greater tuberosity and/or fracture of the inferior rim of the glenoid were the only associated lesion: there was no associated neurovascular lesion reported. Close reduction was useful for Downey et al. (1983), but not for De Laat et al. (1997) as the shoulder redislocated.

Section 6: Axillary artery, suprascapular artery, venous drainage and innervation of the glenohumeral joint

1. Axillary artery:

The axillary artery commences at the outer border of the first rib, which is the apex of the axillary space, as a continuation of the subclavian artery (Figure 2.6.1). It passes through the axilla to terminate at the lower border of teres major at the level of the posterior axillary fold to become the brachial artery. When the arm is abducted to 90° and externally rotated a line drawn from the mid-clavicular point to the medial border of coracobrachialis represents the surface marking of the axillary artery. Proximally the artery is deeply situated whereas distally it is superficial, being covered by skin and fascia. It is divided into three parts by pectoralis minor which crosses it anteriorly. The first part extends from the lateral border of the first rib to the medial border of pectoralis minor, the second part is posterior to pectoralis minor and the third part extends from the lateral border of pectoralis minor to the inferior border of teres major. The first part has the clavicular head of pectoralis major and the clavipectoral fascia anterior, the axillary vein medial, part of serratus anterior and the medial cord of the brachial plexus posterior. The lateral cord of the brachial plexus is superolateral and the posterior cord lateral. The second part has pectoralis major and minor anterior, the medial cord of the brachial plexus medial, the lateral cord lateral and the posterior cord posterior. The third part has pectoralis major, skin and superficial fascia anterior, the axillary vein, ulnar nerve and medial cutaneous nerve of the forearm medial, the musculocutaneous and median nerves lateral and the axillary and radial nerves posterior (Moore et al., 2011; Palastanga et al., 2006; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922).

Branches of the axillary artery:

The superior thoracic artery is a small branch which arises from the anterior aspect of the first part of the axillary artery close to the lower border of subclavius (Appendix 1 Table 2). It runs anteromedially posterior to the axillary vein along the upper border of pectoralis minor then passes deep to pectoralis major between it and pectoralis minor to the side of the thorax. It supplies the upper part of the lateral chest wall, subclavius, pectoralis major and minor, serratus anterior as well as the intercostal muscles of the first and second intercostal spaces. It anastomoses with branches from the transverse scapular, internal thoracic, thoracoacromial and intercostal arteries (Moore et al., 2011; Moore et al., 2010; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946; Robinson, 1922).

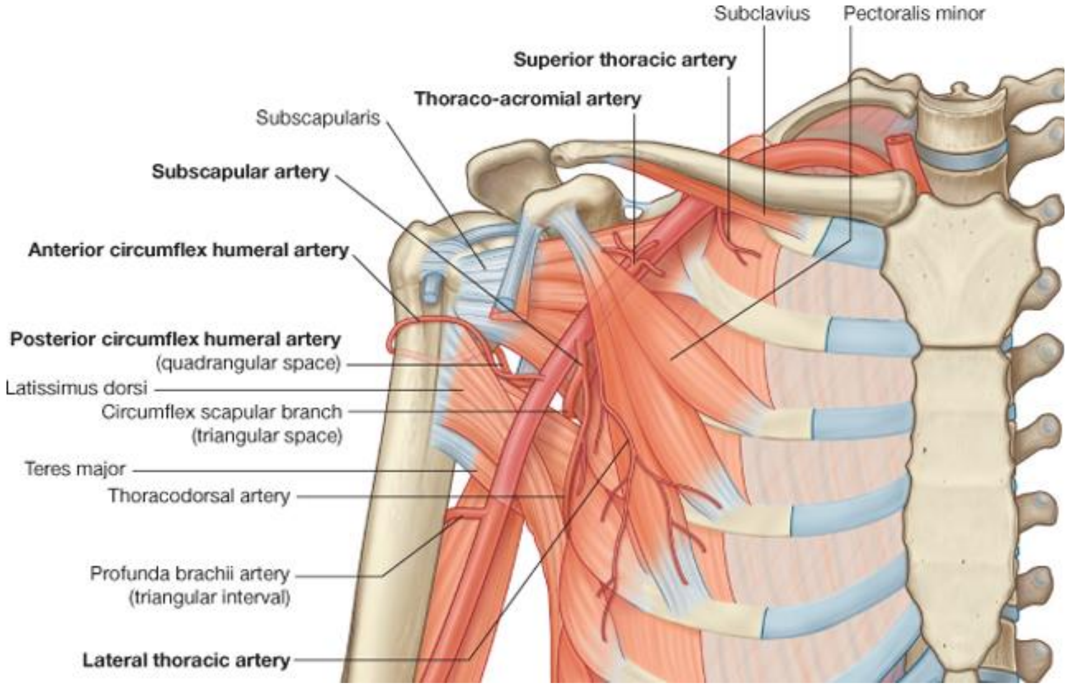


Figure 2.6.1: Branches of the axillary artery; Drake et al. (2005).

The thoracoacromial artery is a short branch arising from the anterior aspect of the second part of the axillary artery just behind the medial border of pectoralis minor, which it then winds around to appear at the superomedial border of pectoralis minor (Appendix 1 Table 3). It passes forward, pierces the clavipectoral fascia (costocoracoid membrane) and terminates deep to the clavicular head of pectoralis major by giving four branches. The acromial branch passes superolaterally crossing the tip of the coracoid process to reach the acromion where it anastomoses with the deltoid branch, the acromial branch of the transverse scapular and the posterior circumflex humeral arteries: it supplies deltoid. The pectoral branch runs inferiorly between pectoralis major and minor anastomosing with the intercostal and lateral thoracic arteries: it supplies the pectoral muscles. The clavicular branch is a long branch which runs superomedially towards the sternoclavicular joint and anastomoses with the superior thoracic artery, branches from the transverse scapular artery and the first perforating branch of the internal thoracic artery: it supplies the sternoclavicular joint and adjacent muscles. The deltoid branch passes laterally between pectoralis major and deltoid alongside the cephalic vein as far as the deltoid insertion where it anastomoses with the acromial branch and the anterior circumflex humeral artery: it supplies deltoid, pectoralis major and skin (Moore et al., 2011; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922).

The lateral thoracic artery, also known as the external mammary artery, arises from the anterior aspect of the second part of the axillary artery just behind the lateral margin of pectoralis minor. It has a variable origin and may arise from the thoracoacromial, suprascapular or subscapular arteries instead (Appendix 1 Table 1). It descends along the lateral (axillary) border of pectoralis minor and gives branches to the breast, as well as muscular branches to the pectoral muscles, the axillary lymph nodes and superficial fascia of the superior part of the abdominal wall. It anastomoses with the intercostal, subscapular and pectoral branch of the thoracoacromial arteries (Moore et al., 2011;

Moore et al., 2010; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922).

The subscapular artery is considered to be the largest of the axillary artery branches and is the major blood supply of the posterior axillary wall. It arises from the posterior aspect of the third part of the axillary artery running along the inferior border of subscapularis for 2–3 cm before terminating into two main branches: the circumflex scapular and thoracodorsal arteries (Appendix 1 Table 4). The circumflex scapular artery winds round the lateral border of the scapula leaving the axilla through the triangular space to gain access to the posterior scapular region where it contributes to the anastomoses around the scapula. In the triangular space it gives an infrascapular branch to the subscapular fossa to anastomose with branches from the transverse cervical and transverse scapular arteries. It also gives a branch which descends along the lateral border of the scapula as far as the inferior angle in addition to muscular branches to teres minor and major and deltoid. The thoracodorsal branch runs along the lateral border of the scapula as far as the inferior angle accompanied by the thoracodorsal nerve. It then anastomoses with branches from the lateral thoracic and intercostal arteries (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922).

The posterior circumflex humeral artery arises from the lateral aspect of the third part of the axillary artery behind the origin of the anterior circumflex humeral artery and passes posteriorly, accompanied with the axillary nerve, through the quadrangular space to reach the posterior scapular region before winding round the surgical neck of the humerus deep to deltoid (Appendix 1 Table 5). It gives muscular branches to deltoid, teres major and minor and the long and lateral heads of triceps; an acromial branch runs superiorly towards the acromion to anastomose with the acromial branches of the transverse scapular and thoracoacromial arteries; an ascending branch courses laterally along the long head of triceps and anastomoses with the profunda brachii artery; an articular branch is given off to the shoulder joint; a nutrient branch to the humeral head and terminates by ramifying in deltoid and anastomosing around the surgical neck of the humerus with the anterior circumflex humeral artery and ascending branch of the profunda brachii (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946).

The anterior circumflex humeral artery is smaller than the posterior circumflex humeral artery and arises from the lateral aspect of the third part of the axillary artery as a single branch or in common with the posterior circumflex humeral artery (Appendix 1 Table 6). It runs laterally deep to both coracobrachialis and the short head of biceps brachii anterior to the surgical neck of the humerus to anastomose with the posterior circumflex humeral artery. At the intertubercular sulcus it gives an ascending branch supplying the shoulder joint and muscular branches supplying the surrounding muscles (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946; Robinson, 1922).

Anastomosis around the scapula:

There is an efficient anastomosis between the first part of the subclavian artery and the third part of the axillary artery. The anastomosis occurs in and around the infraspinous fossa and includes: (1) the suprascapular artery from the thyrocervical trunk which reaches the upper border of the scapula and then runs in the supraspinous fossa to approach the infraspinous fossa; (2) the deep branch of the transverse cervical (dorsal scapular) artery, from the thyrocervical trunk of the first part of the subclavian artery, which runs inferiorly along the medial border of the scapula to join the anastomosis in the infraspinous fossa; (3) the subscapular artery which runs inferiorly along the lateral border of the scapula joining the anastomosis in the infraspinous fossa; (4) the circumflex scapular artery which crosses the axillary border of the scapula to approach the infraspinous fossa and join the anastomosis; and (5) lateral branches of the posterior intercostal arteries also share in the anastomosis around the scapula (Figure 2.6.2) (Moore et al., 2011;Moore et al., 2010; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922).

In the literature it has been noted that each part of the axillary artery can have variations which may occur solely or in combination with others. Based on this, these variations have been classified as follow:

- Combined variations of all parts of the axillary artery.
- Variation of the 1st part of the axillary artery only.
- Variation of the 2nd part of the axillary artery only.
- Combined variations of the 2nd and 3rd parts of the axillary artery.
- Variation of the 3rd part of the axillary artery only.

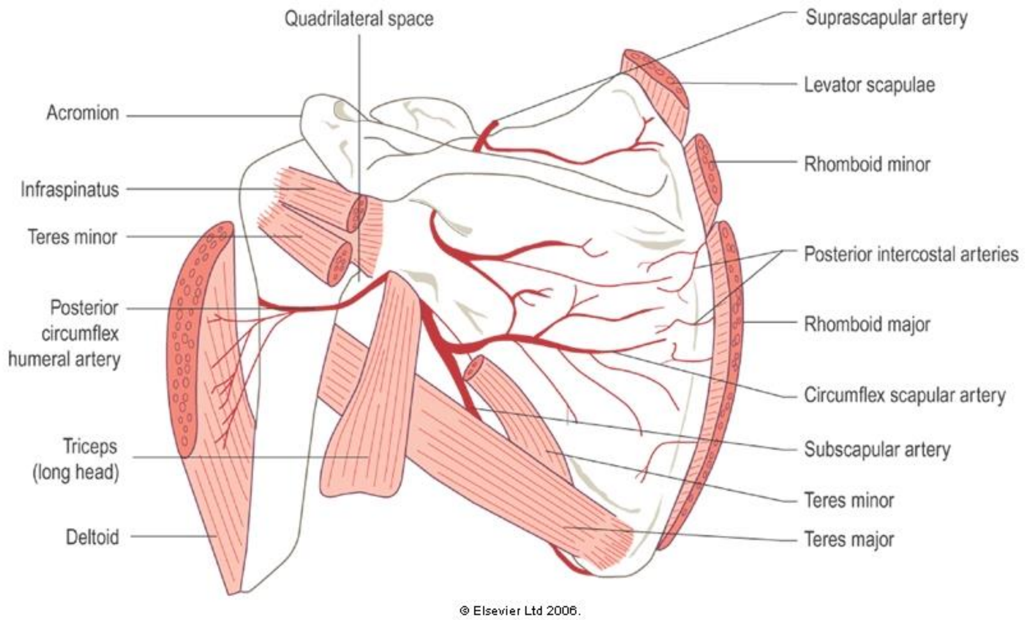


Figure 2.6.2: Vessels involved in supplying the shoulder region, together with those involved in the scapular collateral anastomosis Palastanga et al. (2006) Anatomy and Human Movement, 5th edition.

Combined variations of all parts of the axillary artery:

Variations in the origin of branches from the axillary artery have been reported in the literature. Huelke et al. (1959) observed the superior thoracic artery arising from the first part of the axillary artery in 86.6% (n=77) of cases, from the second part in 2.2% (n=2), the subclavian artery in 5.6% (n=5), the thoracoacromial artery in 1.7% (n=2), the lateral thoracic artery in 1.7% (n=2) and was absent in 2.2% (n=2). Furthermore, the thoracoacromial artery arose from the first part of the axillary artery in 29.8% (n=27), the second part of the axillary artery in 68.5% (n=61) and lateral thoracic/subscapular/brachial artery in 0.6% (n=1): it was absent in 1.1% (n=1). The lateral thoracic artery arose either from the first part of the axillary artery or its branches (thoracoacromial or superior thoracic artery), the second part of the axillary artery or its branches (thoracoacromial, subscapular or thoracodorsal artery), or the third part of the axillary artery or its branches (subscapular or thoracodorsal artery). The posterior circumflex humeral artery originated from the third part of the axillary artery in common with the anterior circumflex humeral artery, the subscapular artery, the deep brachial artery or as a common origin with the anterior circumflex humeral artery (1.1%, n=1) and from other arteries. The anterior circumflex humeral artery arose from the third part of the axillary artery (80.3%, n=71) or as a common trunk with the posterior circumflex humeral artery (11.2%, n=10), deep brachial artery (1.7%, n=2) or from other arteries (0.6%, n=1) (Huelke et al., 1959). In a study of Asian cadavers, variation of the axillary artery was observed in 62.5% (n=30) of specimens while the remaining 37.5% (n=10) was as given in standard anatomy textbooks. Branching pattern variations were found in 30 specimens. Six different types of variation were reported: (I) the lateral thoracic artery arose from the subscapular artery; (II) the thoracoacromial artery was absent; (III) the deltoacromial and clavipectoral arteries arose from the thoracoacromial trunk in 7.5% (n=3); (IV) a common trunk arose from the third part of the axillary artery giving rise to the anterior and posterior circumflex humeral, subscapular and profunda brachii arteries in 12.5% of specimens (n=5); (V) a common trunk giving rise to both anterior and posterior circumflex humeral arteries as well as the profunda brachii in 17.5% (n=7) of specimens; and (VI) a double posterior circumflex humeral artery arising from the third part of the axillary and brachial arteries was found in one specimen (2.9%, n=1) (Astik and Dave, 2012). Also, following dissection of 25 cadavers to evaluate variation of axillary artery branching patterns, the first part showed no variation, while 12% (n=6) of the second part showed variations, in which 6% (n=3) had 3 extra branches named alar branches, 4% (n=2) gave the subscapular artery and 2% (n=1) an unreported superficial branch which ran superficially in the arm and cubital fossa and then deep to the flexor retinaculum terminating by sharing in the formation of the superficial palmar arch. Variation of the third part of the axillary artery occurred in 4% (n=2) giving rise to the circumflex scapular artery, in 2% (n=1) two anterior circumflex humeral arteries were observed, and in 20% (n=5) a common trunk giving rise to the subscapular and posterior circumflex scapular arteries. In addition, the axillary artery was found to be accompanied by two axillary veins in 8% (n=4) of specimens (Samata Gaur et al., 2012).

Daimi et al. (2010) report a 70 year old Indian male in the first part of the right axillary artery gave rise to the lateral thoracic and thoracoacromial arteries, the second part to another thoracoacromial, the radial and subscapular arteries, the latter dividing into circumflex scapular and thoracodorsal branches; the third part gave a double posterior and one anterior circumflex humeral arteries. A 60 years male cadaver with bilateral axillary artery variation has been reported by Arquez (2014). The first part gave no branches; the second part gave the thoracoacromial, lateral thoracic and a common trunk giving the thoracodorsal, circumflex scapular, subscapular and posterior circumflex humeral arteries, while the third part gave the anterior circumflex humeral artery only. Chakravarthi et al. (2012) reported an unusual pattern of the axillary and brachial arteries in which the first part of the axillary artery had no branches, the second part gave two main trunks the first of which gave off superior thoracic, clavicular and pectoral branches and the second lateral thoracic, posterior circumflex humeral, thoracodorsal and subscapular branches and continued as the circumflex scapular artery. The third part of the axillary artery gave acromial, deltoid and anterior circumflex humeral branches. In the mid-arm the brachial artery gave a common trunk giving rise to the profunda brachii and superior ulnar collateral artery. Earlier Baral et al. (2009) reported that in a Nepalese cadaver the first part of the axillary artery had no branches, the second part gave the thoracoacromial artery and a common trunk from which arose the lateral thoracic, thoracodorsal, subscapular, circumflex scapular and posterior circumflex humeral arteries, while the third part gave the anterior circumflex humeral artery.

The classical branching pattern of the axillary artery has been reported in only 77% (n=20) of specimens examined (Farhan and Selman, 2010). The subscapular artery arose from the lateral thoracic artery in 7%; the lateral thoracic artery from the subscapular artery in 5%, which then gave rise to the circumflex scapular and thoracodorsal arteries in 2.5%; the posterior circumflex humeral artery arose from the subscapular, brachial and lateral thoracic arteries in 11%, 9% and 2% respectively. In an unusual case Saralaya et al. (2008) observed that the second and third parts of the axillary artery did not give any branches, whereas the first part gave the superior thoracic artery and a large collateral branch they named the common subscapular trunk which gave rise to the thoracoacromial, thoracodorsal, posterior circumflex humeral, lateral thoracic and circumflex scapular arteries, with the latter giving the anterior circumflex humeral artery.

Variations in the subclavian/axillary arterial system have also been observed in 7.5% (n=3) of specimens studied (Saeed et al., 2002). These comprise an aberrant right subclavian artery arising from the arch of the aorta, a common subscapular circumflex humeral trunk observed bilaterally (3.8%) arising from the third part of the axillary artery giving double posterior circumflex humeral and subscapular arteries, which in turn gave rise to the circumflex scapular and thoracodorsal arteries, and a common thoracohumeral trunk bilaterally in one individual (1.9%) emanating from the second part of the axillary artery and giving arise to the lateral thoracic, subscapular (4mm diameter) and posterior circumflex humeral (9mm diameter) arteries: the anterior circumflex humeral artery was absent (Saeed et al., 2002).

Variation of the 1st part of the axillary artery only:

The axillary artery was unilaterally found in 60 years old female with an unusual variation: the first part of the axillary artery gave a common branch named a common subscapular trunk which gave arise to the thoracoacromial, lateral thoracic, thoracodorsal, circumflex scapular, and anterior and posterior circumflex humeral arteries: the second and third parts did not give any branches (Saralaya et al., 2008). A common trunk arising from the first part of the left axillary artery was observed in a Caucasian male cadaver which gave the thoracoacromial and subscapular arteries: the subscapular artery then gave the posterior circumflex humeral and lateral thoracic arteries following which it bifurcated into circumflex scapular and thoracodorsal arteries (Goldman et al., 2012). An early origin of the left subscapular artery from the axillary artery (at the lower border of the second rib) has been reported, giving origin to the thoracoacromial, posterior circumflex humeral and lateral thoracic arteries (Goldman, 2008). A bilateral variation of the subscapular artery was also seen arising from the first part of the axillary artery. On the right side it branched into the lateral thoracic, thoracodorsal and a large posterior circumflex humeral, which later gave rise to the circumflex scapular artery, while on the left side it gave the lateral thoracic, thoracodorsal and circumflex scapular arteries. It has also been noted that both anterior and left posterior circumflex humeral arteries originate from the first part of the axillary artery (Lee and Kim, 2008). A rare variation of the first part of the axillary artery bifurcating into lateral and medial branches has been observed in a 72 year old Caucasian male (Yotova and Novakov, 2004). The lateral branch gave the lateral thoracic artery after which it continued in the arm as the brachial artery, whereas the medial branch descended and at the lower border of pectoralis minor gave (1) the subscapular artery with a diameter of 4mm which bifurcated into thoracodorsal (2.8mm in diameter) and circumflex scapular (2.8mm in diameter) arteries, (2) the anterior circumflex humeral artery (2.8mm in diameter), and (3) the posterior circumflex humeral artery (1mm in diameter) after which it passed into the arm as the profunda brachii (Yotova and Novakov, 2004). In a 50 years old male the first part of the right axillary artery was observed to give rise to the thoracodorsal and lateral thoracic arteries, while the subscapular artery arose from the medial side of the second part of the axillary artery and gave the posterior circumflex humeral, thoracodorsal and circumflex scapular arteries: the first part of the left axillary artery gave the subscapular artery only (Durgun et al., 2002).

Variation of the 2nd part of the axillary artery only:

Variations of the second part of the axillary artery has a wide spectrum extending from branches which usually arise from other parts of the axillary artery to branches associated with the brachial artery. A common trunk arising as a branch from the second part of the axillary artery has been reported in the literature, but the pattern of its branches is variable. In a meta-analysis Srimathi (2011) reported a common trunk arising from the second part of the axillary artery which gave rise to the thoracoacromial, lateral thoracic, subscapular and posterior circumflex humeral arteries: the anterior circumflex humeral artery originated from the third part of the axillary artery. Bhat et al. (2008) reported a case with a right common trunk arising from the second part of the axillary artery which gave all branches usually arising from the axillary artery apart from the superior thoracic and anterior circumflex humeral arteries, which arose from the first and the third parts respectively. Mehrdad and Sadeghi (2007) also reported a common trunk in a male cadaver arising from the second part of the left axillary artery, but it only bifurcated into subscapular and lateral thoracic arteries. Recently, Chitra and Anandhi (2013) reported a common trunk arising from the second part of the axillary artery which gave rise to the subscapular, lateral thoracic and posterior circumflex humeral arteries: the authors added that the first part of the right axillary artery gave origin to the superior thoracic artery but the thoracoacromial trunk was absent with its four branches arising directly from the second part: the third part gave origin to the anterior circumflex humeral artery. Dual trunks, superficial and deep, from the second part of the axillary artery have been reported by Yohannan and Ravindran (2013): the superficial trunk descended in the arm as the brachial artery, whereas the deep trunk trifurcated into subscapular, and anterior and posterior circumflex humeral arteries. The second part of the axillary artery, in a 55 year male cadaver, gave rise to three branches: thoracoacromial, subscapular, which bifurcated into circumflex scapular and thoracodorsal arteries, and a collateral branch, which gave rise to both anterior and posterior circumflex humeral arteries as well as accessory subscapular arteries supplying the subscapular region (Verma et al., 2014).

Jetti et al. (2013) reported an extraordinary and rare variation in which the brachial artery arose from the second part of the axillary artery, descended in the arm entering the cubital fossa and terminated by dividing into radial and ulnar arteries. Not only can the brachial artery arise from the axillary, but the radial artery has also been reported arising from the second part of the axillary artery (Waghmare et al., 2009). In a meta-analysis the radial artery had a higher origin 3.67% (n=4) of specimens arising from (1) the middle of the brachial artery, (2) the left axillary artery, (3) the left axillary artery, and (4) the left brachial artery: the axillary artery gave origin to the radial artery in 1.83% (n=2) (Claassen et al., 2010). According to Gupta et al. (2012) the second part of the axillary artery has been observed to give rise to the superficial ulnar artery bilaterally.

Combined variations of the 2nd and 3rd parts of the axillary artery:

Variations of both the second and third parts of the axillary artery are extremely diverse. A common trunk arising from either the second or third part is one of the most common variations reported; furthermore, its branching pattern is also variable (Appendix 1 Table 7). Shantakumar and Mohandas Rao (2012) reported the second part of the right axillary artery giving a common trunk which bifurcated into lateral thoracic and subscapular arteries, whereas the third part gave origin to both the anterior and posterior circumflex humeral arteries. Agrawal et al. (2013) reported that the second part of the right sided axillary artery gave only the thoracoacromial artery whereas the third part gave the anterior circumflex humeral artery and a common trunk which divided into posterior circumflex humeral artery, lateral thoracic, subscapular, circumflex scapular and muscular branches. Similarly, Jain et al. (2013) reported the second part of the left axillary artery giving only the thoracoacromial artery and the third part the anterior circumflex humeral artery and a common trunk, which gave the lateral thoracic, posterior circumflex humeral, thoracodorsal and circumflex scapular arteries. More recently, Sarkar et al. (2014) reported a bilateral identical variation of the axillary artery in which the second part gave only the thoracoacromial branch while the third part gave the anterior circumflex humeral artery and a common trunk, which then divided into posterior circumflex humeral, subscapular, and lateral thoracic arteries. According to Bolwar (2011) a right side common trunk of origin, at the junction between the second and third part of the axillary artery, has been observed to give rise to the lateral thoracic and subscapular arteries. Jurjus et al. (1999) reported a bilateral bifid axillary arteries which divided into regular and variant arteries. The second part of the regular artery gave rise to the thoracoacromial artery and two posterior branches, while the third part gave both anterior and posterior circumflex humeral arteries and then continued as the brachial artery. Whereas the second part of the variant artery gave origin to the thoracoacromial, two long thoracic and two posterior branches while the third part gave the subscapular and a common trunk for an additional two circumflex humeral branches. On the right side the variant artery terminated as the profunda brachii and muscular branches supplying triceps on the left side.

The second part of the right axillary artery has been observed to give rise to the subscapular artery which bifurcated into the posterior circumflex humeral and lateral thoracic arteries, while the ulnar artery as well as the anterior circumflex humeral artery originated from the third part of the axillary artery (Swamy et al., 2013). Troupis et al (2014) observed that the second part of the right axillary artery gave the superior thoracic and pectoral branches before its third part bifurcating into superficial and deep trunks: the deep trunk gave rise to branches of the thoracoacromial, anterior and posterior circumflex humeral and subscapular arteries, which then trifurcated into circumflex scapular, thoracodorsal and lateral thoracic arteries; it terminated as a deep brachial artery: the superficial trunk descended in the forearm as a brachial artery.

The incidence of these variations has been quantified by Olinger and Benninger (2010) who stated that the thoracodorsal and subscapular arteries arise from the lateral thoracic artery in 7.2% (n=6) and 5.4% (n=4) and are bilateral in 66.7% and 44.4% respectively. In contrast, the lateral thoracic artery was found to arise from the subscapular artery in 4.2% (n=3) and was bilateral in 57.1%. In 2.4% (n=2) the subscapular artery was absent and therefore the lateral thoracic artery observed to give the circumflex scapular and thoracodorsal arteries: it is seen bilaterally in 50%. The posterior circumflex humeral artery is seen to arise directly from the axillary artery in 77.1% (n=64) (87.5% bilateral), circumflex scapular artery in 12% (n=10) (40% bilateral), deep brachial artery in 8.4% (n=7) (71.4% bilateral) and lateral thoracic artery in 1.2% (n=1). Recently, in another study of 30 cadavers, the subscapular arose from the second part of the axillary artery in 6.66% (n=2) (50% on each side), whereas the third part of the axillary artery gave: (1) a common trunk which bifurcated into anterior and posterior circumflex humeral arteries in 20% (n=6) (33.33% left side, 66.66% right side), (2) a common trunk which bifurcated into posterior circumflex humeral and subscapular in 8.33% (n=2) (20% left side, 80% right side) (Karambelkar et al., 2011).

Variation of the 3rd part of the axillary artery only:

Incidence:

Some studies have tried to quantify the incidence of variations of the third part of the axillary artery, but there is a broad and diverse range reported in the literature (Appendix

1 Table 8a, b). According to Hartley and Marquez (2012) only 56% (n=13) of the third part of the axillary artery gives rise to the classical branches: subscapular, anterior and posterior circumflex humeral arteries, with the profunda brachii and both the anterior and posterior circumflex humeral arteries arising from the subscapular artery in 6% (n=1). Pandey et al. (2004) observed that variation of the third part of the axillary artery was only seen in 14.33% (n=51) and predominantly in females with a male to female incidence of 12.33% (n=18) and 40.63% (n=13) respectively, with the right side being 17.42% (n=31) and left side 11.24% (n=20): four classifications have been suggested. In the first the axillary artery is divided into medial and lateral divisions, being 6.16% (n=9) in males and 15.63% (n=5) in females with 7.87% (n=14) on the right and 4.49% (n=8) on the left: the anterior circumflex humeral artery originated from the lateral division in 3.37% (n=6), whereas the subscapular artery arose persistently from the medial division of the axillary artery. In the second the axillary artery terminated by dividing into deep and superficial trunks, being 2.74% (n=4) and 6.5% (n=2) in males and females respectively: it was seen in right shoulders in 3.37% (n=6) and left in 2.81% (n=5): the profunda brachii arose from the deep division in 2.25% (n=4) while the superficial division gave no branches. In the third group the axillary artery trifurcated into lateral, intermediate and medial divisions, being 2.74% (n=4) in males and 6.25% (n=2) in females: it was seen on the right in 3.37% (n=6) and left in 1.69% (n=3). The lateral division gave the anterior circumflex humeral and brachial arteries; the intermediate trunk divided proximally into superficial and deep branches which descended to the cubital fossa to become the ulnar and radial arteries; while the medial division terminated as the subscapular artery. In the fourth group the axillary artery tapered in 0.68% (n=1) males and 12.50% (n=4) females being 2.81% (n=5) in the right side and 2.25% (n=4) on the left side.

Kachlik et al. (2011) reported that variation of the axillary artery was only observed in 3% (n=4) of specimens. Case one: the left axillary artery trifurcated into three arteries (1) profunda brachii, which gave an accessory thoracodorsal branch as well as a common trunk that divided into anterior and posterior circumflex humeral arteries and (2) brachial artery, which descended to terminate in the cubital fossa by dividing into radial and ulnar branches, and (3) subscapular artery, which bifurcated into thoracodorsal and circumflex scapular branches. Case two: the axillary artery having common trunks: the first trunk gave the superior thoracic and lateral thoracic arteries, then the axillary artery divided into the brachial artery, which descended to the cubital fossa and divided into radial and ulnar arteries, and another common trunk which gave rise to the profunda brachii and both anterior and posterior circumflex humeral arteries. Case three: the third part of the left axillary artery divided into the brachial artery and a common trunk which gave rise to both anterior and posterior circumflex humeral arteries as well as the profunda brachii. Case four: the third part of the axillary artery divided into the brachial artery and a common trunk which gave both anterior and posterior circumflex humeral, subscapular and circumflex scapular arteries. In an evaluation of Indian cadavers Majumdar et al. (2013) observed variations of the axillary artery in 10% (n=7), but noted that it was more common in males (71.42%, n=5) and on the right (80%, n=4): in females it was observed on the left side only. Case 1: the right circumflex scapular artery originated from the third part of the axillary artery and the subscapular from the second part bifurcating into lateral thoracic and thoracodorsal branches. Case 2: the right side posterior circumflex humeral artery originated from the subscapular artery. Case 3: the right side posterior circumflex humeral artery arose from the subscapular artery in addition to a superficial branch originating from the third part of the axillary artery running subcutaneously and ramifying on the lateral side of the thoracic wall. Case 4: an alar thoracic artery arising from the third part of the axillary artery running and ramifying on the lateral wall of the thoracic cavity. Case 5: the right lateral thoracic artery arising from the subscapular artery. Case 6: the left side lateral thoracic artery was absent. Case 7: a right common circumflex humeral artery arising from the third part of the axillary artery which then gave origin to both the anterior and the posterior circumflex humeral arteries.

Few analyses have provided the incidence of variations of each branch of the third part of the axillary artery. For instance, Patnaik et al. (2000) have drawn attention to the fact that the variability of origin of the subscapular artery is as high as 80% (n=20), arising either directly as a single artery from the third part of the axillary artery (58%, n=14), or as a common trunk with the posterior circumflex humeral artery (18%, n=4), profunda brachii (2%, n=1) or deep division of the brachial artery (2%, n=1), while in the other 20% (n=5) the subscapular artery arises from the first part of the axillary artery in 16% (n=4) (6% as a single branch, 10% as a common origin with the lateral thoracic artery in 6% and posterior circumflex humeral artery in 4%), and is absent in 4% (n=1). They also state that the posterior circumflex humeral artery arises from the third part of the axillary artery in 96% (n=24) (as a single branch in 58% (n=14) and as a common origin with the subscapular and anterior circumflex humeral in 22% (n=5) and 16% (n=4) respectively), or from rare branches of the third part, such as the brachial artery in 2% (n=0.5) and profunda brachii in 2% (n=0.5), while in 4% (n=1) the posterior circumflex humeral artery originated from the second part of the axillary artery as a common origin with the subscapular and lateral thoracic arteries. Finally, the authors add that the anterior circumflex humeral artery originated from the third part of the axillary artery in 96% (n=24) (being a single branch in 80% (n=20) and as a common origin with the posterior circumflex humeral artery in 16% (n=4)), and from the profunda brachii and brachial artery in 2% (n=0.5) each. Khaki et al. (2011) reported absence of the subscapular artery in which case the circumflex scapular artery arose directly from the third part of the axillary artery. Recently Hattori et al. (2013) reported that the subscapular and posterior circumflex humeral arteries were observed to follow the classical branching pattern in 33.9% (n=21), suggesting that variations of the subscapular and posterior circumflex humeral arteries are as high as 66.1% (n=41). The availability, variability and measurements of the subscapular artery were investigated by Jesus et al. (2008): the subscapular artery was present in 96.7% (n=58) with an average calibre of 5mm and length of 18mm. It arose from the second part of the axillary artery in 15% and the third part in 76.7%: it gave collateral branches in 67.2% (n=39) of shoulders. The subscapular artery bifurcated into the circumflex scapular and thoracodorsal arteries in 81.1% (n=49), and trifurcated to give additional muscular branches in 18.9% (n=11).

However, Garry and Marquez (2008) disagreed with Hattori et al. (2013) in reporting that 82.6% (n=38) of subscapular arteries follow the classical anatomical pattern by arising from the posterior aspect of the third part of the axillary artery and dividing into circumflex scapular and thoracodorsal arteries. They also added that the posterior circumflex humeral artery arose from either the subscapular or thoracodorsal artery in only 6.53% (n=3). Furthermore, Rowsell et al. (1984) reported that the subscapular-thoracodorsal arterial system was persistent in all specimens.

Variations in the site and course of its branches:

The site of origin and course of the thoracodorsal as well as the anterior and posterior circumflex humeral arteries from the axillary artery have been assessed by Rao et al. (2012). They reported a case in which the right posterior circumflex humeral artery arose from the lower border of the third part of the axillary artery and passed through the lower triangular space before passing upwards and laterally to reach the surgical neck of the humerus. Whereas Konarik et al. (2009) reported the posterior circumflex humeral artery arising from the axillary artery at the distal end of pectoralis major then running deep to latissimus dorsi and teres major to supply the shoulder joint: it also gave the profunda brachii artery. A rare bilateral accessory thoracodorsal artery has been reported arising from the third part of the axillary artery and descending inferolaterally to terminate in latissimus dorsi (Natsis et al., 2005). According to Chen et al. (2012) the anterior circumflex humeral artery ran horizontally approaching the humeral shaft obliquely to terminate in deltoid.

Common origin:

The other type of variation of the third part of the axillary artery is a common origin which invariably branches. Meyer et al. (2005) reported the anterior and posterior circumflex humeral arteries having a common origin in 66.66% (n=4): both the anterior and posterior circumflex humeral arteries surrounded the humerus, gave branches and coursed proximally to supply the humeral head. Shashikala and Panjakash (2012) observed that the subscapular and posterior circumflex humeral artery arose from a common origin in 5% (n=0.5): the anterior circumflex humeral artery arose as usual.

Common trunk:

Rao et al. (2008) reported a case in which the third part of the axillary artery had a common trunk, which gave origin to the subscapular artery from its medial aspect and both the anterior and posterior circumflex humeral arteries from its posterolateral aspect: it terminated after passing along the radial groove by dividing into superior and inferior ulnar collateral branches in the arm. The left side of the third part of the axillary artery was reported to have a common trunk; however it gave rise to the subscapular, anterior and posterior circumflex humeral, profunda brachii and ulnar collateral arteries (Rao et al., 2008). The right side of an adult cadaver has also been reported with a common trunk of the third part of the axillary artery, which trifurcated into the lateral thoracic and both anterior and posterior circumflex humeral arteries (Satyanarayana et al., 2012). The third part of the left axillary artery was also observed to have a common trunk origin, trifurcating into (1) the thoracoacromial artery, which gave acromial and clavicular branches, (2) the lateral thoracic artery and (3) the subscapular artery, which gave a common trunk for the anterior and posterior circumflex humeral arteries (Pant et al., 2013).

Superficial and deep branches:

The other variation of the third part of the axillary artery is that it divides into superficial and deep trunks with each trunk giving variable branches. Cavdar et al. (2000) were the first to describe the right third part of the axillary artery dividing into main branches, superficial brachial and deep brachial branches. The deep brachial branch gave the subscapular and both anterior and posterior circumflex humeral arteries, while the main trunk of the deep brachial artery continued in the arm, giving the profunda brachii and terminating after crossing the bicipital aponeurosis by giving a small branch to the radial side of the forearm. The superficial brachial artery descended on the medial side of the arm reaching the cubital fossa and divided into radial and ulnar arteries. George et al. (2007) report a unilateral third part axillary artery dividing into superficial and deep trunks: the deep trunk gave rise to the subscapular, profunda brachii, anterior and posterior circumflex humeral arteries, while the superficial trunk descended to become the brachial artery in the forearm. More recently, in a male Desai et al. (2011) stated that the third part of the right axillary artery divided into superficial and deep branches, with the superficial branch giving the superior and inferior ulnar collateral arteries and terminating before reaching the cubital fossa by dividing into radial and ulnar arteries: the deep branch gave the subscapular, profunda brachii and both anterior and posterior circumflex humeral arteries and then coursed in the arm deep to the superficial branch entering the cubital fossa as a common interosseous artery which divided at the upper border of the interosseous membrane into anterior and posterior interosseous arteries. VijayaBhaskar et al. (2006) observed a case in which the third part of the axillary artery divided into superficial and deep brachial arteries. The superficial branch coursed in the arm without branching giving both the radial and ulnar arteries in the cubital fossa; the deep branch gave rise to the subscapular, profunda brachii, and anterior and posterior circumflex humeral arteries. Based on the Sawant et al. (2012b) study, the incidence of superficial and deep trunks was observed in 2% (n=2) of the shoulders, the superficial trunk continuing as the brachial artery in the arm, and the deep trunk bifurcating into an anterior division, which gave the anterior and posterior circumflex humeral as well as profunda brachii arteries, and the posterior division the subscapular, which bifurcated into circumflex scapular and thoracodorsal arteries.

Lateral and medial branches:

Division of the third part of the axillary artery into lateral and medial branches is another variation reported in the literature: again their branches are variable. The third part of the left axillary artery has been observed to give rise to one main trunk (length of 2.5 cm), which divided into two main lateral and medial branches (Soubhagya et al., 2006). The lateral branch gave the superior ulnar collateral, which ran to the elbow joint and a common humeral circumflex which gave both the anterior and posterior circumflex humeral arteries; the posterior circumflex humeral artery continued as the profunda brachii in the arm. The medial branch was the subscapular artery which gave the circumflex scapular artery and continued as the thoracodorsal artery (Soubhagya et al., 2006). A very rare and interesting variation of the third part of the left axillary artery was reported to give a common trunk bifurcating into lateral and medial branches; the lateral branch supplied biceps brachii and coracobrachialis, while the medial branch descended to the hypogastric region to anastomose with the superficial epigastric artery: it has been named the thoracoepigastric artery (Kogan and Lewinson, 1998). Patnaik et al. (2001) have also reported the third part of the axillary artery dividing into two branches; the first branch crossing the median nerve from medial to lateral in the mid-arm passing into the forearm as the radial artery, while the second branch gave the anterior and posterior circumflex humeral, subscapular and profunda brachii arteries, the latter passing deep to the median nerve from lateral to medial and continuing as the ulnar artery in the forearm. It has also been observed to be bilaterally variable (Salpek et al., 2007): on the left side the axillary artery divided into two branches, the brachial artery, which coursed in the forearm reaching the cubital fossa and dividing into radial and ulnar arteries, the profunda brachii, which gave rise to both the anterior and posterior circumflex humeral and subscapular arteries; on the right side the third part of the axillary artery had a 0.5 cm long common trunk which gave the circumflex scapular, thoracodorsal and posterior circumflex humeral arteries. The authors also noted that the subscapular artery was absent.

Brachial artery and profunda brachii:

Division of the third part of the axillary artery into brachial and profunda brachii arteries has been observed. Sargolzaei-Aval and Arab (2013) report the left axillary artery dividing into two common trunks, a superficial trunk which descended in the arm and divided into radial and ulnar arteries in the cubital fossa, and a deep brachial artery, which gave rise to the subscapular, anterior and posterior circumflex humeral, profunda brachii and terminated as the inferior ulnar collateral artery. Furthermore, Thakur et al. (2013) reported an unusual double brachial artery which was seen in 1% (n=1) of specimens: the third part of the axillary artery duplicated into the usual brachial artery, which continued its classical course, and a variant branch, which descended in the arm, forearm and terminated in the superficial palmar arch, giving muscular branches along its course. Furthermore, the third part of the axillary artery trifurcated into a subscapular trunk, superficial and deep brachial arteries: the subscapular trunk gave the circumflex scapular, thoracodorsal and posterior circumflex humeral arteries, while the deep brachial artery gave rise to the anterior circumflex humeral artery and the superficial brachial artery which gave origin to two profunda brachii arteries running in the spiral groove (Bagoji et al., 2013). Chauhan et al. (2013) reported the profunda brachii artery arising from the third part of the axillary artery in 4% (n=4) of specimens and as a common origin with the posterior circumflex humeral artery in 2% (n=2). Also a Brazilian female has been reported with a bilateral variation in the origin of the deep brachial artery which arose from the subscapular artery and passed to the posterior compartment of the arm with the radial nerve (De Paula et al., 2013). A unique variation has also been reported with a double profunda brachii, the first arising from the brachial artery and terminating in the anastomosis around elbow, while the second arose from the posterior circumflex humeral artery, which then divided into radial and middle collateral branches (Sawant et al., 2012c). In addition, a trunk arising from the third part of the right axillary artery gave the subscapular, anterior and posterior circumflex humeral arteries continuing as profunda brachii in the arm (Naveen et al., 2014). Finally, the right axillary artery was observed to give a collateral branch which in turn gave rise to the subscapular, anterior and posterior circumflex humeral, profunda brachii and ulnar collateral arteries (Venieratos and Lolis, 2001).

Radial and ulnar branches:

Both radial and ulnar and ulnar collateral arteries can have a high origin from the third part of the axillary artery or the brachial artery. Yagain and Anadkat (2012) have reported that the radial artery can be accompanied by the anterior and posterior circumflex humeral as well as the subscapular arising from a common origin from the third part of the axillary artery. It originated just proximal to the origin of the subscapular artery in the arm and descended lateral to the median nerve before running on the lateral aspect of the forearm terminating in the hand as the superficial palmar arch. However, the superior ulnar collateral artery accompanied by the posterior circumflex artery and profunda brachii arose from a common origin of the proximal part of the axillary artery (Teli et al., 2013). A bilateral ulnar artery originating from the axillary artery was reported by Jacquemin et al. (2001): on the right side it had a common origin with the subscapular artery which ran on the medial side of the arm and continued on the medial side of the forearm in its usual course. Natsis et al. (2006) observed that the right superficial ulnar artery arose from the third part of the axillary artery just distal to the subscapular and both anterior and posterior circumflex humeral arteries. It descended lateral to the median nerve in the arm then crossed to the medial aspect of the forearm terminating in the hand as the superficial palmar arch. Furthermore, Yildirim et al. (1999) also reported the superficial ulnar artery arising from the third part of the axillary artery. Finally, a bifid axillary artery has been diagnosed each descending distally to give rise to either the ulnar or radial artery (Bigeleisen, 2004).

2. Suprascapular artery:

The suprascapular artery originates from the thyrocervical trunk of the first part of the subclavian artery (Palastanga et al., 2006; Moore et al., 2010).

Course and relations:

From its origin the suprascapular artery passes posteriorly and inferolaterally posterior to sternomastoid and anterior to scalenus anterior and the phrenic nerve as it approaches the posterior triangle of the neck. It crosses anterior to both the brachial plexus and third part of the subclavian artery before running posterior and parallel to the clavicle and subclavius deep to the posterior belly of omohyoid: it is accompanied by the suprascapular nerve and vein as far as the superior border of the scapula. As the suprascapular artery approaches the superior border of the scapula it courses superficial to the transverse scapular ligament, which separates it from the suprascapular nerve, entering the supraspinous fossa deep to supraspinatus. It then emerges from the spinoglenoid notch into the infraspinous fossa and runs inferiorly as far as the inferior angle of the scapula: it contributes to the anastomosis around the scapula (Gray, 1913; Smith et al., 1983; Hall-Craggs, 1990; Rogers, 1992; Snell, 1995; Monkhouse, 2001; Sinnatamby, 2006; Faiz and Moffat, 2006; Ellis, 2006; Moore et al., 2010).

Branches:

The suprascapular artery gives: (1) branches which share in the anastomosis around the scapula (Abrahams et al., 2011), (2) nutrient branches supplying both the scapula and clavicle (Gray, 1913), (3) an acromial branch which passes through trapezius to supply skin over the acromion as well as anastomosing with the acromial branch of the thoracoacromial artery (Gray, 1913), (4) muscular branches supplying subclavius and sternomastoid in addition to the other muscles of the shoulder girdle (Lumley et al., 1995), (5) articular branches to supply the shoulder and acromioclavicular joints

(Lumley et al., 1995; Gray, 1913), (6) a small subscapular branch which arises at the transverse scapular ligament and passes inferiorly into the subscapular fossa to ramify in subscapularis (Gray, 1913), (7) a suprasternal branch which supplies skin over the superior part of the thorax (Gray, 1913).

Incidence and classification:

In one study (Polguj et al., 2014) the suprascapular artery, nerve and vein have been classified into four types: Type I, (61.3%, n=65) the suprascapular artery runs superior to the transverse scapular ligament while both the suprascapular vein and nerve pass through the suprascapular notch; Type II, (17%, n=18) both vessels pass superior while the nerve passes through the suprascapular notch; Type III, (12.3%, n=13) all the structures pass through the suprascapular notch; Type IV, (9.4%, n=10) includes all other variants. In another study (Yang et al., 2012) the presence of the suprascapular artery was classified into three types: type I, observed in 59.4% (n=60) in which the suprascapular vessels pass above the transverse scapular ligament; type II, observed in 29.7% (n=30) in which the suprascapular vessels run over and beneath the transverse scapular ligament; type III, observed in 10.9% (n=11) in which both suprascapular vessels run below the scapular ligament. It was also observed that in 48.9% (n=50) of specimens all types were found bilaterally.

In an assessment of the relation of the suprascapular artery to the brachial plexus in a European population, the suprascapular artery was found to pass anterior to the brachial plexus (71%, n=71), between the trunks of the brachial plexus (28%, n=28) and posterior to the brachial plexus (1%, n=1) (Dargaud et al., 2002). A 52 year old male presented with pain and progressive weakness of flexion, abduction and external rotation of his left shoulder. Diagnostic arthroscopy revealed that both the suprascapular artery and nerve passed through the suprascapular notch deep to the suprascapular ligament causing suprascapular nerve compression (Houtz and McCulloch, 2013). An accessory suprascapular artery has been reported arising from the third part of the subclavian artery at the lateral border of scalenus anterior, where it coursed beneath the lower trunk of the brachial plexus and then approached the superior border of the scapula. Once the suprascapular artery reached the suprascapular notch it passed deep to the transverse scapular ligament accompanied by the suprascapular nerve, where the classical suprascapular artery passes over the transverse scapular ligament. Both suprascapular arteries contribute in the anastomosis around the scapula (Chen and Adds, 2011). Tubbs et al. (2003), observed that the suprascapular artery passed through the suprascapular notch in 2.5% (n=3) of specimens.

Variations of origin, number, course and branches:

A number of studies have evaluated variations of the suprascapular artery revealing that it has a diverse origin, course and branches. According to Drake et al. (2005) and Moore et al. (2010) the suprascapular artery may arise from the third part of the subclavian artery. Pyrgakis et al. (2013) reported that the suprascapular artery arose from the third part of subclavian artery in 1.61% (n=0.5), being observed in females only: both the suprascapular artery and suprascapular nerve passed through the suprascapular notch without the suprascapular vein. Another variant reported by Mishra and Ajmani (2003) observed the suprascapular artery arising from the first part of the axillary artery in 1.6% (n=0.5) passing posterior to the clavicle and deep to subclavius to approach the superior border of the scapula, where it ran through the suprascapular notch (deep to the transverse scapular ligament): this was observed in three cadavers (6%). It supplied the supraspinous and infraspinous fossae, and gave an acromial branch to the shoulder joint as well as branches which anastomosed with the circumflex scapular artery. Supporting this observation, Adibatti (2010) report a left suprascapular artery arising directly from the first part of the axillary artery running superiorly for a short distance then obliquely posterior to the clavicle to approach the suprascapular notch, where it passed deep to the transverse scapular ligament accompanied by the suprascapular nerve and vein to emerge in the supraspinatus fossa before passing into the infraspinatus fossa.

A case is reported in which the suprascapular arteries arose bilaterally from the third part of the axillary artery instead of the thyrocervical trunk. Each ascended superiorly to pass between the lateral cord anteriorly and the posterior cord posteriorly of the brachial plexus. On both sides, the suprascapular artery passed through the suprascapular notch deep to the transverse scapular ligament accompanied by the suprascapular nerve and vein to emerge into the supraspinatus fossa (Mahato, 2010). Similarly, Shukla et al. (2012) reported a case in which the first part of the axillary artery gave rise to the suprascapular artery: both arteries ran obliquely posterior to the clavicle approaching the suprascapular notch, where they passed through it with the suprascapular nerve and vein terminating in the anastomosis around the scapula. However, Bagoji et al. (2012) report a subscapulo-suprascapular arterial trunk arising from the first part of the right side of the axillary artery, terminating by dividing into three branches: ventral and dorsal branches supply subscapularis, with the suprascapular artery passing with the suprascapular nerve through the suprascapular notch. Another origin variant has been reported by Atsas et al. (2011) in which the left suprascapular artery arose from the internal thoracic (mammary) artery close to its origin from the subclavian artery. It ran posteriorly underneath the medial third of the clavicle to accompany the suprascapular nerve, where it passed over the transverse scapular ligament to terminate in the anastomosis around the scapula.

3. Venous drainage:

Basilic vein:

The basilic vein is always single and is a persistent feature of the upper limb. It arises from the ulnar side of the dorsal venous network and ascends along the medial side of the forearm before running anteriorly to pass anterior to the medial epicondyle of the humerus to enter the medial bicipital furrow. At the level of the coracobrachialis insertion it pierces the deep (brachial) fascia to run along the medial side of the brachial vessels. It continues as a single vessel reaching the lower border of teres major in 23.1% (n=6) of specimens and joins with the medial venae concomitantes of the brachial artery in 53.8% (n=14) and the brachial vein in 23.1% (n=6) before becoming the axillary vein. It is joined by tributaries from the forearm and by the median cubital vein anterior to the elbow, the intermediate cubital vein in 69.8% (n=19) of individuals, the intermediate basilic vein in 23.1% (n=6) and the intermediate basilic vein of the forearm in 3.8% (n=1) (Baptista-Silva et al., 2003; Palastanga et al., 2006). On the other hand, Yang et al. (2012) report that the basilic vein was absent in 5% (n=2). Anaya-Ayala et al. (2011) classified the brachial-basilic vein anatomy into type I, in which the basilic vein joins the brachial vein at the axillary level, seen in 66% (n=281) of patients; type II, in which the basilic vein joins the brachial in the mid-arm or the lower third with duplication of the brachial vein, seen in 17% (n=73); type III, in which the junction is at the mid-arm or the lower third with no duplication of the brachial veins, observed in 17% (n=72). Kaiser et al. (2010) reported a case with a low junction between the basilic vein and a single brachial vein.

Brachial vein:

Classically the brachial veins are two deep venae comitantes accompanying the brachial artery by joining of the radial and ulnar veins in the cubital fossa and terminating by joining the basilic vein to form the axillary vein at the lower border of teres major (Hall-Craggs, 1990; Rogers, 1992; Snell, 1995; Drake et al., 2005; Palastanga et al., 2006; Moore et al., 2010). According to Yang et al. (2012) the brachial venae concomitantes end separately with the basilic vein to form the axillary vein in 72.5% (n=29) or join together to form one common brachial vein in 27.5% (n=11) which then join either the basilic or the axillary vein

However, a common brachial vein has been reported in the literature. Santos et al. (2011) observed a common brachial vein in 73% (n=22) of their specimens which drained directly into the axillary vein in 82% (n=18) and into the basilic vein in 18% (n=4). Kumar et al. (2012) also report a case with a common brachial vein which was formed by union of the radial and ulnar veins and joined the basilic vein at the lower border of teres major to form the axillary vein.

Cephalic vein:

The cephalic vein arises from the lateral end of the dorsal venous arch and receives dorsal veins of the thumb. It runs on the anterolateral aspect of the forearm reaching the elbow and then passes along the lateral side of the biceps tendon approaching the groove anterior to the shoulder between deltoid and pectoralis major, the deltopectoral groove. It runs in the deltopectoral groove to the level of the coracoid process, where it passes medially between pectoralis minor posteriorly and pectoralis major anteriorly. It then pierces the clavipectoral fascia and terminates in the axillary vein at a point inferior to the middle of the clavicle. It receives many tributaries in the forearm and at the anterior aspect of the elbow joint it is connected to the basilic vein by the median cubital vein. It also communicates with the external jugular vein (Palastanga et al., 2006; Yeri et al., 2009; Kim and Han, 2010).

Axillary vein:

The axillary vein is formed by the union of the basilic and brachial veins at the lower border of teres major: it terminates at the outer border of the first rib by becoming the subclavian vein. It accompanies the axillary artery and receives tributaries from the cephalic, subscapular, circumflex humeral, lateral thoracic and thoracoacromial veins (Palastanga et al., 2006; Moore et al., 2010). Yang et al. (2012) observed the axillary vein to be duplicated in 17.5% (n=7) of cases. The anterior circumflex humeral vein drains into the lateral brachial vein in 67.5% (n=27) while the posterior circumflex humeral vein drains either into the axillary (45%, n=18) or subscapular vein (42.5%, n=17). Fujii et al. (2012) report a right side double axillary vein; while George et al. (2007) report a double axillary vein which joined to form a single axillary vein near its termination. An unusual variation was reported by Mahajan et al. (2012) in which the lateral thoracic artery pierced the axillary vein deep to pectoralis minor which they confirmed histologically. Hadimani et al. (2013) also observed branches of the axillary artery perforating the axillary vein.

4. Nerve supply of the glenohumeral joint:

The anterior fibrous capsule is innervated by articular branches from the subscapular (C5, C6), axillary (C5, C6) and lateral pectoral (C5, C6) nerves (Aszmann et al., 1996; Blum et al., 2013)

The subscapular nerves are three in number (upper, middle and lower) arising from the posterior cord of the brachial plexus. The cranial branch divides into two muscular branches which enter the superior aspect of subscapularis: the lateral branch gives a twig to the subcoracoid bursa and then runs deep into the anterior aspect of the fibrous capsule (Aszmann et al., 1996; Palastanga et al., 2006)

The axillary nerve arises from the posterior cord of the brachial plexus (C5, C6). As it winds around the surgical neck of the humerus it gives an articular branch running into the anteroinferior aspect of the fibrous capsule following which it divides into medial and lateral branches: the medial branch supplies the glenoid part of the anteroinferior aspect of the fibrous capsule as well as the axillary recess, while the lateral branch passes inferior to the inferior edge of subscapularis supplying the humeral part of the anteroinferior aspect of the fibrous capsule. It gives muscular branches to teres minor and the long head of triceps and its adjacent fibrous capsule, observed in 28% of specimens (Aszmann et al., 1996; Palastanga et al., 2006; Blum et al., 2013).

The lateral pectoral nerve arises from the lateral cord of the brachial plexus and runs anterior to the axillary vessels to communicate with the medial pectoral nerve. Just before piercing the clavipectoral fascia it gives a small articular branch which passes towards the coracoid process supplying the subacromial and subcoracoid bursae and the anterior acromioclavicular joint (Aszmann et al., 1996; Palastanga et al., 2006).

The posterior fibrous capsule is innervated by articular branches from the suprascapular (C5, C6) nerve in addition to the axillary nerve (Aszmann et al., 1996; Blum et al., 2013).

The suprascapular nerve is a mixed nerve originating from the upper trunk of the brachial plexus (C5, C6) crossing the posterior triangle of the neck to gain access to the suprascapular notch. Before passing deep to the suprascapular ligament it gives a large superior articular branch which passes parallel and above the suprascapular nerve through the suprascapular notch and then runs laterally behind the base of the coracoid process: it gives periosteal twigs and a branch to the coracoclavicular and coracoacromial ligaments. It terminates by dividing into two branches supplying the coracohumeral ligament, subacromial bursa, acromioclavicular joint and adjacent structures. The main suprascapular nerve passes from the supraspinaous to the infraspinous fossa deep to supraspinatus through the spinoglenoid notch to supply supraspinatus and infraspinatus. At the spinoglenoid notch it gives inferior articular branches running laterally to supply the posterior aspect of the fibrous capsule (Aszmann et al., 1996; Palastanga et al., 2006; Blum et al., 2013). In addition, Palastanga et al. (2006) add that the musculocutaneous nerve, which has a root value of C5, 6 and 7, also supplies the glenohumeral joint.

Section 7: Histology of the glenoid labrum

Consistency:

The glenoid labrum has caused confusion as its constitution has been observed to be diverse. It is described as a fibrous ring or fibrous band effectively increasing the depth of the glenoid socket by 9 mm in the superoinferior region and 5 mm in the anteroposterior region, as well as sharing in the overall circumferential depth by 50% (Schafer and Thane, 1892; Robinson, 1922; Howell and Galiant, 1989). Others have described it as a cartilaginous structure (Snell, 1995; Carey et al., 2000; Drake et al., 2005; Palastanga et al., 2006; Sinnatamby, 2006; Moore et al., 2010). One study found that during week 10 of gestation the glenoid labrum was well defined and attached to the glenoid margin, being fibrocellular rather than fibrocartilaginous with collagen fibres; furthermore it was vascular with more capillaries growing in the free margin by week 12½ (Nazir et al., 2014). In contrast, according to Moseley and Overgaard (1962), Cooper et al. (1992), Pfahler et al. (2003) and Bain et al. (2012) the glenoid labrum is composed of dense fibrous tissue with a narrow fibrocartilaginous zone between the articular hyaline surface and glenoid labrum (Figure 2.7.1). Centrally, the fibres are circumferentially oriented, being perpendicular peripherally. A crevice (cleft or fissure) has been observed to lie in the transitional zone between the fibrous glenoid labrum and the hyaline cartilage in 36.36% (n=4) of shoulders: it is characterized by hypercellularity and collagen fibre orientation; however, its function is still unknown. Pfahler et al. (2003) classified shoulders according to their age: group I, less than 40 years; group II, between 40 - 60 years; group III, more than 60 years, with changes in the articular surface, transitional zone, superior and anterosuperior aspects of the glenoid labrum being identified even in group I. Cellularity and vascularity of the labrum and the transitional zone increased with age, being more in group III. The subchondral bone density and trabeculae decreased with age (Pfahler et al., 2003).

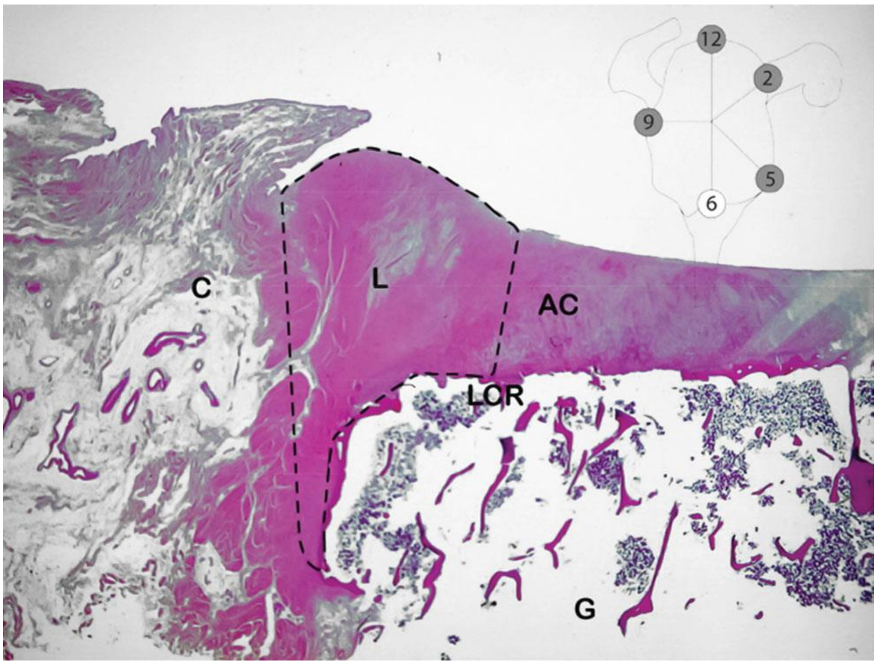


Figure 2.7.1: Histological axial cross section at 6 o'clock. AC, articular cartilage; C, capsule; G, glenoid cancellous bone; L, labrum; LCR, internal labral circumferential ridge. Note the bumper effect of the labrum which is firmly attached on the face of the glenoid Bain et al. (2012)

The amount and size of the fibrocartilage in the glenoid labrum have been evaluated circumferentially using immunohistochemistry, with Ockert et al. (2012) confirming that it has a circumferentially avascular fibrocartilaginous zone constituting up to one third of the glenoid labrum in cross section: the rest was dense fibrous tissue. The amount of fibrocartilage was observed to be greater at 12 and 6 o'clock and suggested to be associated with the insertion of the long heads of biceps and triceps. However, Hideyuki et al. (2005) stated that the anterosuperior aspect of the glenoid labrum has a lesser fibrocartilaginous area with a small attachment site to the underlying glenoid bone giving it a meniscal appearance. In contrast, the anteroinferior aspect of the glenoid labrum has a greater fibrocartilaginous area with a larger attachment site with a meniscus-like appearance. The inferior and posterior aspects of the glenoid labrum have average sized fibrocartilaginous areas, average sites of attachment and were rounded in shape.

Mode of attachment, size and composition:

The glenoid labrum interfaces with the underlying bone through uncalcified fibrocartilage then calcified fibrocartilage integrating Sharpey's fibres to the bone. The collagen fibres of the glenoid labrum at the labrum-articular cartilage interface were not very dense between 11 and 4 o'clock and associated with loose or incomplete attachment of the glenolabral junction, however a complete attachment between the glenoid labrum and the underlying articular cartilage between 5 and 11 o'clock was observed. The glenoid labrum region lying between 10 and 12 o'clock was attached to the apex of the glenoid rim, where in the other regions of the clock face the articular cartilage does not extend to the glenoid edge because the glenoid labrum has a bony foundation and is covered by the glenoid edge. The superior glenoid labrum in cross-section has a free concave articular margin, a loose interface with the articular surface, is relatively mobile and does not help to increase the depth of the glenoid cavity. In contrast the remaining regions of the glenoid labrum in cross-section have a rounded convex surface and well adherent interface with the articular hyaline cartilage (Bain et al., 2012). According to Hill et al. (2008) the glenoid labrum is attached to the underlying glenoid bone by vertical and oblique interweaving fibres with associated Sharpey's fibres anchoring into the superficial bony surface of the glenoid. Whereas the attachment to the underlying hyaline cartilage is by finger-like processes via foramen in the superficial aspect of the hyaline cartilage in association with Sharpey's fibres: it was noted that the region between the glenoid labrum and the hyaline cartilage was cellular suggesting a transitional zone. The interdigitating anchored fibres and Sharpey's fibres attach to the underlying glenoid bone and cartilage in different orientations supporting the idea that the glenoid labrum is subjected to various multidirectional forces. The long head of biceps tendon fuses with the glenoid labrum and the adjacent osseochondral region coherently. As the glenoid labrum has a variable microstructure it is suggested that it could have a role in constraint in order to prevent any damage to other structures.

In an analysis of shoulders, depending on age the shape and size of the glenoid labrum were variable and the consistency ranged from rubbery to firm. Shoulders of individuals in their fifth decade of age at the time of death had a glenoid labrum that was thin and virtually absent. The glenoid labrum extended to cover the peripheral margin of the articular surface in a similar way to the menisci of the knee in the rest of the shoulders. It was emphasized that the glenoid labrum of individuals younger than 30 years at the time of death was firmly attached to the glenoid rim, whereas in individuals over 30 years of age the anterosuperior region of the glenoid labrum was detached in 23.52% (n=4): the size of detachment was found to increase with age, but the fibrous capsule remained attached in all shoulders. The glenoid labrum was sparsely vascularized without any configurative pattern of distribution: the vascularity was observed to decrease with age (Prodromos et al., 1990). Shoulders of foetuses were investigated with the vascular channels proliferating inside the glenoid labrum and glenoid bone increasing with gestational age. They were more obvious by 19 weeks of gestation, occurring with the start of the appearance of collagen fibers and their cells (Lapner et al., 2010).

The mean thickness of the glenoid labrum, which is defined as the distance from the glenoid edge to the anterior edge of the glenoid labrum, starting at 3 o’clock anteriorly to 9 o’clock posterior were 4.03mm, 4.2mm, 4.51mm, 5.14mm, 3.24mm, 3.78mm, and

4.28 mm respectively: there was a significant difference between regions (Rispoli et al., 2009).

The composition of the superior glenoid labrum is collagen fibres, which run circumferentially along with the circularity of the glenoid and some elastic fibres (Arai et al., 2012). Using electron microscopy Nishida et al. (1996) reported that the glenoid labrum consisted of three layers of collagen: the superficial layer being a thin reticular fibrillar network, the second layer a stratified layer while the third layer consisted of densely arranged bundles of fine fibrils which ran parallel to each other but oblique to the glenoid rim. The function of the first and second layers is to act as a bumper counteracting humeral head impaction, while the third layer stabilizes the glenohumeral joint through a cushion effect. Hill et al. (2008) reported three glenoid labrum zones: firstly is a superficial zone about 5 – 10 micrometre in depth consisting of a mesh of multidirectional fine fibrils which are believed to decrease the surface friction of the joint through lubrication; secondly, there are circumferential loose oriented fibres with a grooved pattern: it characteristically vascular and noted to be most common in the anterosuperior region compared to other regions, the main action of this zone was hypothesized to act in a viscoelastic manner by expressing fluid during loading and recovery in unloading allowing the glenoid labrum to counteract any excessive compression applied on any point, besides, it might tether the underlying layer; and thirdly, is the central core which was considered to be the largest, consisting of large dense fibre bundles circumferentially oriented and avascular. This latter layer is thought to aid in transferring the tensile forces from compression and translation of the glenohumeral joint which in turn indirectly reduces the contract stress on the underlying hyaline articular surface.

Neural receptors of the glenohumeral joint have rarely been observed. The first study was by Vangsness et al. (1995) using a modified gold chloride stain. In the fibrous capsule, there were slow adapting Ruffini end organs, rapidly adapting Pacinian corpuscles as well as free nerve ending in the glenohumeral, coracoclavicular and coracoacromial ligaments. Free nerve endings were noted, but could not be confirmed as nerve endings, in the peripheral part of the glenoid labrum as well as the subacromial bursae. The number of neural receptors was not quantified. Mechanoreceptors could not be detected in the glenoid labrum. However, Guanche et al. (1999), using the same stain as Vangsness et al. (1995) reported four neural receptors, these being Golgi, Ruffini and Pacini corpuscles as well as free nerve ending in 45% of the superior glenohumeral ligament, 42% of the middle glenohumeral ligament, 48% of the inferior glenohumeral ligaments, and 47.5% of the fibrous capsule. Only free nerve endings were revealed in the long head of biceps tendon and the attached part of the superior glenoid labrum. According to Machner et al. (1998) proprioceptive sensations of the glenohumeral humeral joint were deficient in posttraumatic anterior glenohumeral instability: a significant improvement of the joint proprioception was achieved 18 months following arthroscopic labral repair which raises the question of whether the sensory nerve fibres of the glenoid labrum play a role in proprioception of the glenohumeral joint.

Section 8: Glenoid labrum lesions, diagnosis, treatment and treatment outcome

1. Glenoid labrum lesions:

Tears of the glenoid labrum cause glenohumeral instability, which can also occur as a result of glenohumeral dislocation and instability. Different mechanisms of injury produce different tears at different sites around the glenoid labrum. The naming of glenoid labrum tears depends on their anatomical site by describing the labrum as a clock face in which the superior aspect is 12 o'clock, the anterior aspect 3 o'clock, the inferior aspect 6 o’clock and the posterior aspect 9 o'clock. An anterior glenoid labrum tear (between 3- 6 o’clock) is known as a Bankart tear (Widjaja et al., 2006); a superior glenoid labrum tear (between 11 – 1 o’clock) is known as SLAP tear (Sanders et al., 2006); a posterior glenoid labrum tear (between 6 o’clock and 11) is known as a reverse Bankart tear (Shah and Tung, 2009); and finally a combination of Bankart, SLAP and reverse Bankart tears it is called 270^0 tear (Figure 2.8.1) (Alpert et al., 2008; Wang et al., 2008; Seroyer et al., 2010).

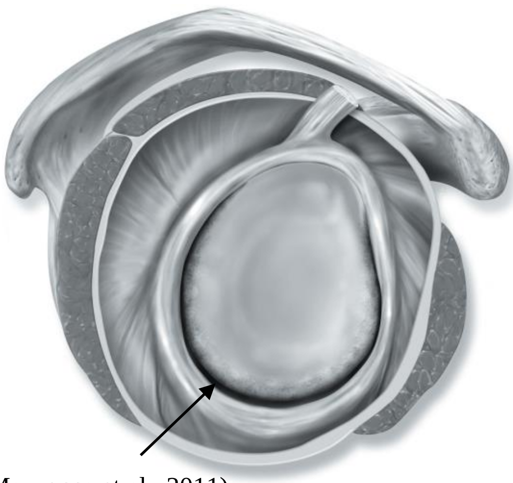


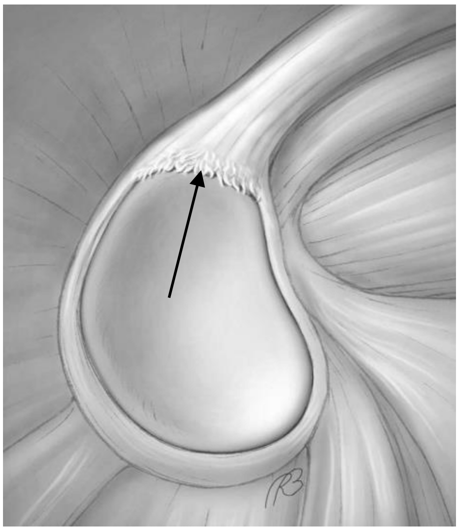
Figure 2.8.1: A 270^0 glenoid labrum tear (Mazzocca et al., 2011)

SLAP lesions classification, pathogenesis and associated lesions:

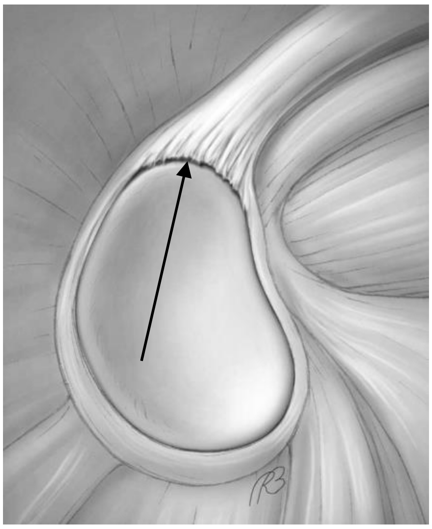
Classification:

Superior labral lesions were first described by Andrews et al. (1985) in a study of baseball pitchers and throwing athletes, being located in the anterosuperior aspect of the glenoid labrum. It was also noted that the long head of the biceps appeared to be continuous with the superior glenoid labrum and that most patients had the anterosuperior glenoid labrum pulled off the glenoid associated with the biceps tendon (Andrews et al., 1985). Classification of SLAP was first coined by Snyder et al. (1990) (cited in Farshad-Amacker, 2013). In an arthroscopic study of injured superior glenoid labra (91% (n=127) male, 9% (n=13) female: average age 38 years) 4 types of tear were identified. In Type I the superior glenoid labrum showed fraying and degenerative changes, but its periphery was still adherent to the underlying bone: this type was observed in 21% (n=29) of individuals (Figure 2.8.2A). In Type II the superior glenoid labrum and long head of biceps tendon are detached from the underlying glenoid bone: this type was observed in 55% (n=77) of individuals (Figure 2.8.2B). In Type III the superior glenoid labrum has a bucket handle tear while the remaining labral tissue remains anchored to the glenoid rim: this type was noted in 9% (n=13) of individuals (Figure 2.8.2C). Finally, in Type IV the bucket handle tear also involved the long head of biceps tendon and was observed in 10% (n=14) of individuals. Furthermore, 29% (n=40) of all glenoid labrum lesions were associated with a partial tear of the rotator cuff, 11% with a full thickness tear and 22% with an anterior Bankart lesion (Snyder et al., 1995) (Figure 2.8.2D). Choi and Kim (2004) reported a case with a similar Type II superior glenoid labrum tear, but could not follow the Snyder et al. (1990) classification due to detachment of the glenoid labrum and exposure of the associated articular cartilage. In a later study by Maffet et al. (1995) only 62% (n=52) of cases fitted the

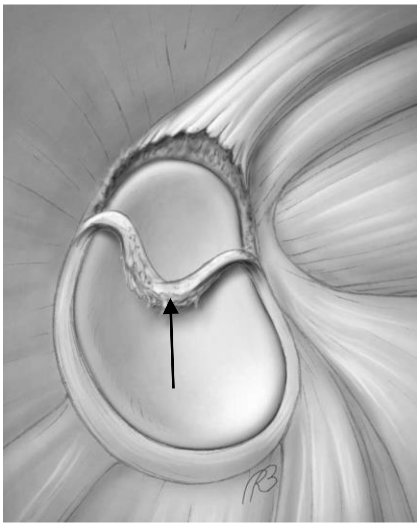
Snyder et al. (1990) classification, with the remaining 38% (n=32) falling into three additional types, which have been added to the Snyder et al. (1990) classification. Type V is a Bankart lesion which extends superiorly and is associated with separation of the long head of biceps (Figure 2.8.2E); Type VI involves separation of the biceps tendon accompanied by an unstable glenoid labrum flap tear (Figure 2.8.2F); and Type VII where there is separation of the labrobicipital complex which extends anteriorly to the middle glenohumeral ligament (Figure 2.8.2G) (Maffet et al., 1995). In their study of SLAP type II lesions Morgan et al. (1998) sub-classified Type II according to its anatomical position: anterior (37%, n=38), posterior (31%, n=32) and both anterior and posterior (31%, n=32): a rotator cuff tear was noted in 31% (n=32) of cases. Lastly, Nord and Ryu (2004 cited in Powell et al., 2004) have added three more types of lesion to the superior glenoid labrum tear classification, these are Type VIII which is a superior glenoid labrum tear extending as far posteriorly as the 6 'o'clock position.(Figure 2.8.2H); Type IX is a pan-labral superior glenoid labrum tear which extends the whole circumference of the glenoid labrum (Figure 2.8.12I); and Type X is a superior glenoid labrum tear associated with a posteroinferior glenoid labrum tear (Figure 2.8.2J) (Powell et al. 2004).



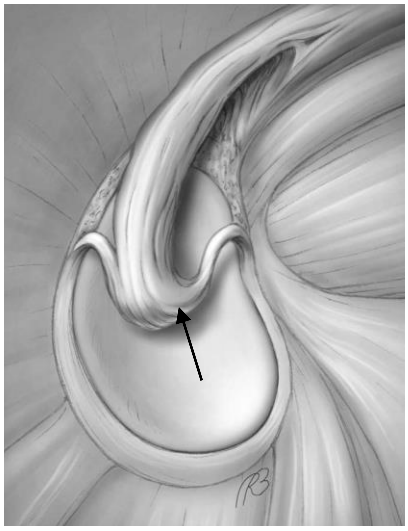
A: SLAP I



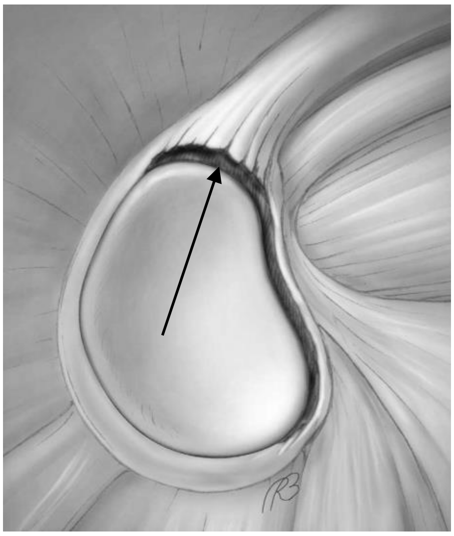
B: SLAP II



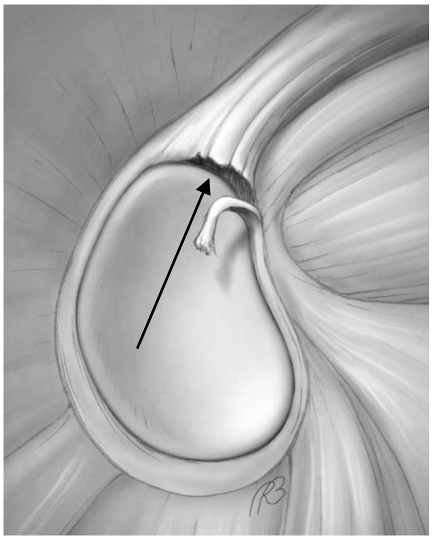
C: SLAP III



D: SLAP IV

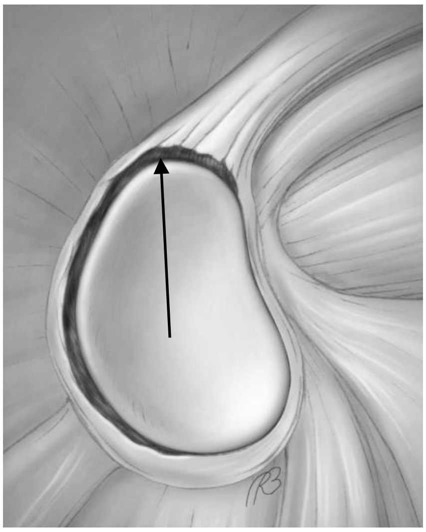


E: SLAP V

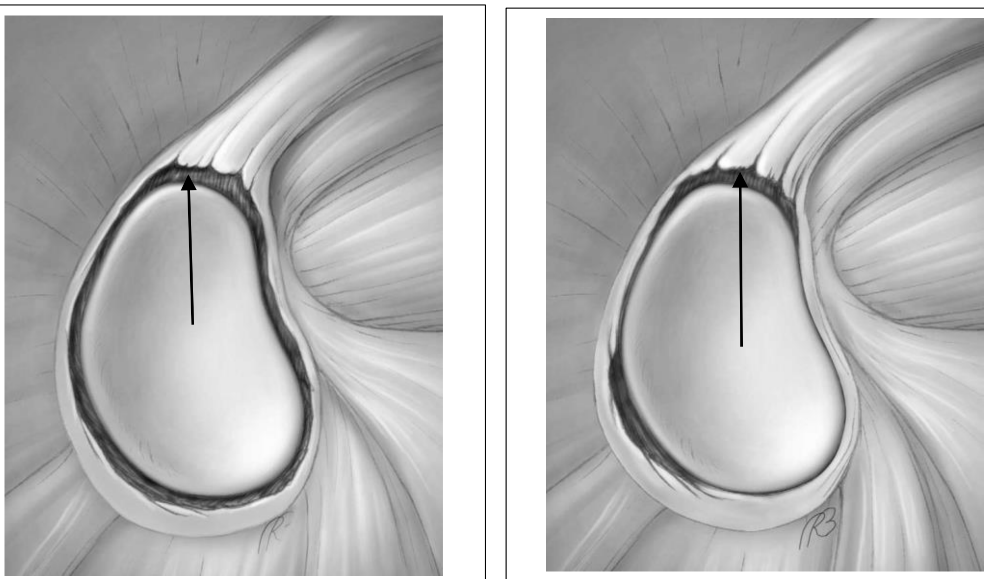


F: SLAP VI

G: SLAP VII



I: SLAP VIII



J: SLAP IX

K: SLAP X

Figure 2.8.2: Types of SLAP lesions of the glenoid labrum (Powell et al., 2004)

Pathogenesis of SLAP

The biomechanical aetiology of SLAP lesions is still unclear. In the literature there are two theories of pathogenesis which can be considered arising from acute and chronic traumatic causes.

Acute traumatic causes:

Falling on an outstretched hand is an example of an acute traumatic cause leading to a SLAP lesion due to direct contact of the humeral head against the superior part of the glenoid labrum and the long head of biceps (Synder et al., 1995; Sanders et al., 2006). Clavert et al. (2004) investigated 10 cadaveric shoulders to assess the SLAP outcome of falling on an outstretched hand, as a secondary impact of the humeral head against the glenoid labrum. Five shoulders simulating a forward fall all showed Type II SLAP lesion, whereas of the five shoulders in which a backward fall was simulated only 2 showed a SLAP type II lesion.

Chronic traumatic causes:

Repetitive overhead activities have been postulated to induce SLAP lesions. In arthroscopy of baseball pitchers and other throwing athletes during which biceps brachii was stimulated resulting in the long head of biceps tendon becoming taut the glenoid labrum was pulled off the glenoid (Andrew et al., 1985). The strain put on the superior glenoid labrum was measured using linear transducers on fresh frozen shoulders during the simulated movements: early cocking, late cocking, acceleration, deceleration and then follow through. The strain [strain is the elongation (stretch) when load is applied: stress is what is applied to the tissue] increased significantly on the anterior and posterior aspects of the superior glenoid labrum in late cocking, which could be correlated with detachment of the labrum (Pradhan et al., 2001). A three-dimensional mesh model of the superior half of the labrum glenoid complex has been created to assess the stress distribution in the glenoid labrum in overhead throwing sports during simulated phases of pitching: the highest stress at the long head of biceps was recorded in the deceleration phase which could be the cause of a SLAP lesion (Yeh et al., 2005). To determine the pathogenesis of a superior labral anteroposterior lesion (SLAP) Type II Shepard et al. (2004) reported that generation of a SLAP Type II lesion can be achieved with a posterior-directed load on the long head of biceps tendon; the resulting SLAP lesion Type II can be the result of multimicrotrauma, pitching mechanisms and shoulder instability. Furthermore, correlation between external rotation of the glenohumeral joint due to changing rotator cuff muscle force and superior anteroposterior glenoid labrum tear (SLAP) Type II has been demonstrated in fresh frozen cadaveric shoulders. A decrease in the strength of subscapularis, due to repetitive throwing or fatigue, leads to an increase in both external rotation and contact pressure of the glenohumeral joint which causes a superior labrum anteroposterior lesion Type

II associated with a rotator cuff tear (Mihata et al., 2009). An anterosuperior impingement of the glenohumeral joint can be the result of a biceps pulley lesion in association with partial tears of the supraspinatus and subscapularis tendons leading to increased anterior humeral translation (Habermeyer et al., 2004). There is an association between anterosuperior impingement of the glenohumeral joint and SLAP lesions (Gerber and Sebesta, 2000). Moreover, the correlation between a Buford complex and SLAP lesions has been retrospectively demonstrated: a Buford complex lesion was found in 2.5% (n=6) of cases, 83.3% (n=5) of which had a SLAP lesion and required surgical intervention. In the remaining cases a SLAP lesion was found in 17.5% (n=40). The conclusion, therefore is that there is an association between Buford complex and SLAP lesions (Bents and Skeete, 2005). Brue et al. (2008) report a case of a 16 year boy complaining of right shoulder pain after trauma: arthroscopy revealed a SLAP Type IV associated with a Buford complex.

In a study of shoulder arthroscopies conducted to evaluate the relationship between variations of the glenoid labrum and its pathology a sublabral foramen was seen in 18.5% (n=20) of shoulders with a Buford complex also being found in 6.5% (n=7). In these shoulders it was noticed that the incidence of SLAP lesion was significantly higher than in the remaining shoulders (Ilahi et al., 2002). Variations of the posterosuperior glenoid labrum and rotator cuff were found to be correlated with the type of sport undertaken. Lesions of the posterosuperior glenoid labrum were noted in 44% (n=22) of patients (fraying in 95.4% (n=21), cracking in 18.1% (n=4), detachment of the superior and posterior aspects in 40.9% (n=9)). Rotator cuff tears were observed in all individuals, being partial in 35% (n=18) and complete in 14% (n=7). SLAP lesion Type II was also reported in 25.5% (n=13) of individuals (Dewan et al., 2012).

Pfahler et al. (2003) grouped shoulders according to age: group I, between 18 to 40 years; group II, between 41 to 60 years; group III, between 61 to 89 years. Using macroscopic dissection, histology and radiology superior glenoid labrum and biceps anchor tears were seen in group I, whereas in groups II and III a complete tear of the glenoid labrum, which included the whole circumference, was observed. The majority of labral tears were in the superior part of the glenoid labrum (at 12 o'clock), followed by the anterosuperior (at 2 o'clock) with the inferior (at 6 o'clock) and posterior (at 9 o'clock) aspects had fewer defects. There is also a significant increase in glenoid labrum tears with increasing age (Pfahler et al., 2003).

In an arthroscopic MRI study Tirman et al. (1994) noted a SLAP lesion was associated with a cystic-appearing mass in all cases: the tear-cystic complex was observed anteriorly in 10% (n=2), superiorly in 45% (n=9) and posteriorly in 45% (n=9). Joint instability was present in 55% (n=11) of patients (Tirman et al., 1994). A SLAP lesion can be a cause of glenolabral cystic lesion formation (Kessler et al., 2007). Pagnani et al. (1995) reported that an isolated SLAP lesion without involvement of the long head of biceps brachii does not have any significant effect on glenohumeral joint translation; in contrast significant joint translation is produced if the long head of biceps is detached.

Bankart lesion:

A Bankart lesion is defined as an anterior glenoid labrum tear (between 3- 6 o’clock) (Widjaja et al., 2006), although Mizuno et al. (1993) earlier stated between 2 and 6 o’clock. It is an essential finding in traumatic recurrent shoulder dislocation (Ito et al., 2005), being the main cause of deficiency of the inferior glenohumeral ligament labrum complex leading to anterior glenohumeral joint dislocation. The incidence of anterior glenohumeral dislocation due to Bankart lesions is 92.1% (n=279) (Mizuno et al., 2005). Sugimoto (2004) noted a Bankart lesion in 52% (n=46) of cases. Bankart lesion and Hill-Sachs defect, which is an injury due to posterolateral osteochondral compression of the humeral head against the glenoid rim (Widjaja et al., 2006), frequently occur in anterior glenohumeral joint dislocation. In an MRI investigation the incidence of Bankart or Hill-Sachs lesions in primary glenohumeral joint dislocation is similar to recurrent dislocation, being 67% (n=10) versus 70% (n=32) for Hill-Sachs lesions and 73% (n=11) versus 72% (n=33) for Bankart lesions (Widjaja et al., 2006). In contrast, 25% of an isolated Hill-Sachs defect increases the glenohumeral joint translation significantly but is not responsible for the recurrent dislocation of the joint (Sekiya et al., 2012).

According to Wischer et al. (2002) a Perthes lesion, which is a variation of a Bankart lesion in which the scapular periosteum is stripped medially but stays attached, is accompanied by partial avulsion of the anterior glenoid labrum causing instability of the glenohumeral joint. Of 75 patients anterior labral ligamentous periosteal avulsion was seen in 12% (n=9) (Sugimoto, 2004). Patients suffering from recurrent glenohumeral dislocation were evaluated by MRI and arthroscopy: lesion of the glenoid labrum was observed in 92% (n=23): anterior labroligamentous periosteal sleeve avulsion (ALPSA) in 12% (n=3), Bankart lesion in 32% (n=8), complex classic Bankart accompanied with ALPSA in 32% (n=8) and complex ALPSA associated by Perthes in 16% (n=4) (Song et al., 2006).

According to Ito et al. (2005) MRI has the ability to diagnose Bankart lesion in only 60% of cases. Nevertheless, shoulders with traumatic recurrent anterior glenohumeral joint dislocation demonstrated that excellent visualization and detection of a Bankart lesion can be achieved with abduction and external rotation of the glenohumeral joint because it tenses the lesion (Ito et al., 2005). Similarly, Perthes lesion can only be diagnosed by MRI with abduction and external rotation of the glenohumeral joint (Wischer et al., 2002).

The effect of Bankart lesion associated with rotator cuff tear on stability of the glenohumeral joint demonstrated a significant increase in glenohumeral translation in a Bankart lesion combined with a tear of the supraspinatus tendon. Therefore it is suggested that repair to both the rotator cuff and Bankart lesion is undertaken to prevent recurrent glenohumeral joint dislocation (Shin et al., 2012).

Posterior labral tear:

A posterior glenoid labrum tear (between 6 o'clock and 11) is known as a reverse Bankart tear (Shah and Tung, 2009). Repeated exposure to trauma led to detachment of the posterior glenoid labrum in athletes without capsular injury or instability (Mair et al., 1998). Shoulder pain and instability in football and non-football players have been assessed, using MRI arthrograms, to evaluate the susceptibility of the posterior glenoid labrum to injury. A glenoid labrum tear was observed in 96% (n=26) of shoulders in footballers, 55% (n=11) of which had a posterior glenoid labrum tear which was classified into two subgroups: labral detachments (67%, n=10) and substance labral tears (33%, n=5). In contrast, 78% (n=108) of the non-football players had a normal glenoid labrum: tear of the glenoid labrum was noted in 22% (n=31), being posterior in 7% (n=10) and anterior in 15% (n=21) (Escobedo et al., 2007). An isolated posterior glenoid labrum tear has been reported associated with pain and limitation of movement on teeing off: MRI revealed tears of the posterior glenoid labrum. Reattachment of the posterior glenoid labrum was undertaken with the individual back to playing golf 7 months later (Faustin et al., 2007). A further case is reported of posterior glenoid labrum tear with detachment and a loose body due to direct trauma to the shoulder; there was also posterior glenohumeral joint instability (Fitzcharles and Charles, 2012).

Circumferential labral tear:

Circumferential labral tears have been reported in three patients. Case I: a male with a history of full inferior and anterior glenohumeral dislocation; MRI revealed posterior labral, SLAP and anteroinferior labral tears. Arthroscopy showed a circumferential labral tear: 6 months following repair the individual was back to normal activity. Case II: a male with a history of full inferior subluxation of the glenohumeral joint; MRI showed a full thickness supraspinatus tear associated with Bankart lesion and posterior labral tear. Arthroscopy revealed a circumferential labral tear: the patient fully recovered after 6 months. Case III: a male with a history of full inferior and anterior glenohumeral dislocation, MRI showed Bankart and SLAP lesions. Arthroscopy demonstrated a circumferential tear in the glenoid: the patient improved but discontinued follow up (Dikens et al., 2012).

Pathology of the glenoid labrum:

Twenty six overhead-throwing athletes with associated impingement pain as well as a rotation cuff deficit were compared to 26 individuals in a control group. All underwent MR arthrograms for posterior labrocapsular complex evaluation. The mean labral length and caspulolabrum length for the control and athletic groups were 4.9mm, 5.4mm and 6.4mm, 8.8mm respectively: it was concluded that the posteroinferior capsule and the glenoid labrum was thicker in the athletic group which could be attributed to the deficit of internal rotation (Tuite et al., 2007). Ossification of the glenoid labrum can cause progressive motion loss and pain. Subhas et al. (2008) reported a case with right shoulder pain and loss of shoulder movement due to ossification caused by melorheostosis. Another case of a patient complaining of right shoulder pain with limitation in movement at the glenohumeral joint was observed to have calcification of the superior glenoid labrum. Dissection of the calcified part of the superior glenoid labrum was undertaken and the patient completely recovered with full range of movement of the glenohumeral joint (Cho and Rhee, 2007).

2. Diagnosis of glenoid labrum lesions:

Clinical examination:

Several clinical examinations are available which can facilitate the diagnosis of glenohumeral and glenoid labrum pathologies. Kibler et al. (2009) evaluated patients using eight clinical tests, these being (i) Yergason's, which is performed by flexing the elbow joint to 90°, stabilized against the anterior aspect of the thorax, with pronation of the forearm, the examiner manually counteracts supination when the patient rotates the arm externally against resistance: a positive test means the existence of pain over the bicipital sulcus, (ii) bear hug, by placing the hand of the effected shoulder on the contralateral shoulder the examiner then tries to put his hand on the anterior aspect of the forearm of the patient attempting to raise or pull the patient's hand off his shoulder: a positive test leads to pain with resistance over the anterior aspect of the effect shoulder, (iii) belly press, the patient is sitting and applying pressure with his hand on his belly, the examiner pushes against his elbow, if the patient cannot fully internally rotate and pushes against his belly, the elbow will drop backward and the test is deemed positive, (iv) Speed's, performed with 90° flexion of the glenohumeral joint, extension of the elbow and supination of the forearm, the examiner applies resistance to the flexed arm: a positive test produces pain over the bicipital groove, (v) anterior slide, the patient is in a standing position and places the hand of the involved arm on the ipsilateral hip with the thumb pointing backwards. The examiner puts one hand on the glenohumeral joint and the other on the elbow of the same side and applies an axial load in an anterosuperior direction from elbow to shoulder: a positive test produces pain on the anterior or posterior joint line, (vi) O'Brien's, the patient is in a standing position with flexion of the glenohumeral joint to 90° and 10° of horizontal adduction with the thumb in internal rotation. The examiner puts his hand over the patient's elbow and applies a resistant pressure and asks the patient to rotate the arm internally and externally: a positive test is considered if the pain is at the joint line and is evoked in internal rotation and disappears in the externally rotated position, (vii) upper cut, which is performed by putting the glenohumeral joint in a neutral position, flexion of the elbow to 90°, supination of the forearm and the patient making a fist. The patient is asked to rapidly bring the hand up and toward the chin. The examiner places his hand over the patient's fist and counteracts the movement: a positive test produces pain over the anterior portion of the glenohumeral joint, and finally (viii) modified dynamic labral shear, which is performed while patient is in a standing position by flexion of the elbow to 90^0 and abduction of the glenohumeral joint in the scapular plane to 120^0 then externally rotates to tightness after that guided into maximal horizontal abduction: a positive test is considered if pain or a painful click is induced in the joint line. All of the above are correlated with surgery. For long head of biceps tendon pathology the bear hug and upper cut tests were observed to be the most sensitive (79% and 73% respectively), in contrast the belly press and Speed's test were the most specific (85% and 81% respectively). The upper cut was found to be the most accurate (77%), whereas for glenoid labrum pathology the modified dynamic labral shear showed sensitivity, specificity and accuracy of 72%, 98% and 84% respectively. The combination of the upper cut and Speed's tests were found to be better in the diagnosis of biceps pathology compared to other tests. On the other hand a combination of the modified dynamic labral shear and O'Brien's best identified glenoid labrum lesions (Yergason, 1931; Bennett, 1998; Tokish et al., 2003; Barth et al., 2006; O'Brien et al., 1998; Kibler, 1995; Kibler et al., 2009). Parentis et al. (2006) state from their study that the best sensitive diagnostic tests for SLAP type II lesion, in order, were active compression, Hawkins, Speed, Neer and then Jobe relocation. In another study of patients, diagnosed arthroscopically to have SLAP type II, Oh et al. (2008) performed seven clinical tests, which were sensitive and specific in diagnosis (sensitive such as: O'Brien, apprehension, Whipple and compression rotation; specific such as: biceps load II, Yergason and Kibler tests), and reported that a combination of two sensitive tests and one specific test enhanced the efficacy of diagnosis with sensitivity and specificity of 75% and 90% respectively. Supporting this, Walsworth et al. (2008) reported that a combination of physical examination tests showed better results than applying a single test in the diagnosis of glenoid labrum tears.

Kim et al. (1999) report that the sensitivity, specificity, positive predictive value, negative predictive value and Kappa coefficient of the biceps load test were 90.9%, 96.6%, 83%,98% and 0.846 respectively. Kim and jerk tests were also considered to be reliable in detection of posteroinferior glenoid labrum lesions (Kim et al., 2005). The sensitivity, specificity, positive predictive value and negative predictive of the Kim test were 80%, 94%, 73% and 96%, whereas the sensitivity, specificity, positive predictive value and negative predictive of jerk test were 73%, 98%, 88% and 95%. It was concluded that the jerk test was more sensitive for posterior glenoid labrum lesions, whereas Kim was better in inferior glenoid labrum lesions. Sixty one patients were evaluated by the passive compression test to diagnose SLAP lesions in association with arthroscopy and found to be effective and reliable with sensitivity, specificity positive predictive value and negative predictive value were 81.8%, 85.7%, 87.1% and 80.0% respectively (Kim et al., 2007).

In contrast, the active compression, anterior slide and compression rotation tests were correlated with arthroscopy: the results were unreliable and not significantly different, consequently the decision for surgery should not rely on these tests only. The active compression test was the most sensitive test (47%), the anterior slide the most specific test (84%), that with the highest positive predictive value was the active compression (10%), the highest overall accuracy was the anterior slide test (77%) and the lowest overall accuracy was the active compression test (54%) (McFarland et al., 2002). SLAP lesions were evaluated by active compression, anterior slide, crank and speed tests: the anterior slide test was found to be poor in SLAP lesion diagnosis and it was suggested that the best was the active compression test then crank test and lastly the speed test should be used by clinicians (Meserve et al., 2009). The crank and O'Brien tests were a found to be insensitive and unreliable in the diagnosis of glenoid labrum tears (Stetson and Templin, 2002).

MR arthrography:

Developments in imaging technology, in particular magnetic resonance arthrography (MRA), has enabled clinicians to detect glenoid labrum and bicipital tendon lesions (Holzapfel et al., 2010; Knesek et al., 2013). MRA of the glenohumeral joint was correlated with arthroscopy by Fotiadou et al. (2013) who reported that MRA is very accurate in diagnosis of any glenoid labrum lesions with sensitivity, specificity, diagnostic accuracy, positive predictive value, negative predictive value of 96%, 80%, 95%, 98% and 66% respectively. According to Cvitanic et al. (1997) the sensitivity of MRA was found to be significant in the diagnosis of anterior glenoid labrum tears in abducted and externally rotated shoulders compared to the neutral position. The inter- and intra-observer variability of MRA was analysed and revealed that the sensitivity and specificities of the three readers in the detection of a SLAP lesion, in correlation with arthroscopy, were 88.6%/93.3%, 90.9%/80% and 86.4%/76.7% (Holzapfel et al., 2010). MRA was effective without intra-articular injection (Wallny et al., 1988). MRI arthrogram has been performed in correlation to arthroscopy and MRI arthrography; arthroscopy revealed SLAP tears in 31.25% (n=25) of patients: type II (88%, n=22), type III (8%, n=2) and type III (4%, n=1). The sensitivity, specificity and accuracy of each were 92%, 84% and 86%; 92%, 82% and 85%; 84%, 69% and 74% respectively; MRI is therefore concluded to be reliable and accurate in the diagnosis of glenoid labrum tears (Jee et al., 2001). In contrast, MRA is less useful in the preoperative evaluation of the glenoid labrum because it has the ability to diagnose major tears or detachment of the glenoid labrum (Zanetti et al., 2001).

MRI:

Using MRI in the diagnosis of glenoid labrum pathology is very useful and effective (Shellock et al., 2001). Non-contrast MRI has been correlated with arthroscopy and resulted in an accurate outcome with a sensitivity, specificity, accuracy, false positive and false negative values of 98%, 89.5%, 95.7%, 3.8% and 1.9% respectively (Connell et al., 1999). Glenoid labral tears greater than 180^0 can be also identified on preoperative MRI using the characteristics of young, heavily muscled patients associated with either extensive posterior labral pathology or multiple sites of labral injury (Lindauer et al., 2005). MRI on asymptomatic professional baseball pitchers revealed glenoid labrum abnormalities in 79% (n=11) of cases (Miniaci et al., 2002). MRI of the glenohumeral joint without intra-articular injection was effective in the diagnosis of capsulolabral pathology of the glenoid labrum (Monu et al., 1994; Rafii et al., 2004). The sensitivity of MRI was tested in patients diagnosed by arthroscopy to have a sublabral foramen or Buford complex: the sensitivity, specificity, accuracy were 94%, 80% and 90% respectively (Tuite et al., 2002).

Comparison between MRI and MRA:

In a study of 12 superior, 9 posterior and 5 anterior glenoid labral tears diagnosed by arthroscopy conventional MRI detected 9 of the 12 superior (sensitivity, 75%; specificity, 100%), 7 of the 9 posterior (sensitivity, 78%; specificity, 92%) and 3 of the 5 anterior (sensitivity, 60%; specificity, 94%) labral tears. In contrast MRA identified 9 of the 12 superior (sensitivity, 75%; specificity, 100%), 8 of the 9 posterior (sensitivity, 89%; specificity, 100%), and all of the anterior (sensitivity, 100%; specificity, 100%) labral tears. MRA was therefore more effective, informative and superior to MRI in the diagnosis of labro-ligamentous and all SLAP lesions (Yoneda et al., 2001; Woerthler and Waldt, 2006; Major et al., 2011; Smith et al., 2012).

Others diagnostic tools which have been recently used:

1. Double contrast CT scan arthrography: this is easy to perform and provides accurate details of the glenohumeral joint, the glenoid labrum and fibrous capsule (Haynor et al., 1984).

2. Axillary arthrotomography: this has been applied to shoulders and revealed glenoid labrum tears in surgically confirmed shoulders with one false positive. It provided characteristic details regarding the integrity of the glenoid labrum giving diagnostic quality images (Kleinman et al., 1984).

3. Sonography: in a cadaveric study to evaluate the accuracy of sonography in the diagnosis of a glenoid labrum lesion in correlation with arthroscopy Taljanovic et al. (2000) reported that the concordance was 86% (n=69) in the differentiation of glenoid labrum pathology from the normal glenoid labrum with sensitivity, specificity, positive predictive value, negative predictive value and accuracy of 63%, 98%, 94%, 86% and 88% respectively. In the differentiation of glenoid labrum tears from other labral

pathologies the sensitivity, specificity, positive predictive value, negative predictive value and accuracy were 67%, 99%, 67%, 99% and 98% respectively.

4. Double-contrast arthrography: this has been applied to patients and revealed successful results in 66% of individuals with labral abnormalities (Mink et al., 1979).

3. Management of glenoid labrum lesions:

Management of SLAP lesions:

The outcome of SLAP lesions is variable in the literature (Table 2.8.1). There are a number of operative procedures available for the treatment of SLAP lesions, including staples, screws, arthroscopic sutures, transosseous sutures and bioabsorbable tacks (Knesek et al., 2013).

SLAP type I: this is usually a simple degenerative tear of the glenoid labrum with the long head of biceps tendon often remaining intact. The treatment of choice is simple debridement (DaSilva et al., 2008)

SLAP type II: several treatment procedures are available, but arthroscopic repair by suture anchors is considered to be effective and gives good outcome (Yung et al., 2008). Double row repair has been shown to be effective in the restoration of stability compared with single row repair (Kim et al., 2011). According to DaSilva et al. (2008) a SLAP type II lesion is characterized by a tear of the superior glenoid labrum and detachment of the long head of biceps, therefore the goal is to re-attach the labral-bicipital anchor complex by debridement of both the superior glenoid labrum, using a 4.5 mm shaver, and the bony bed, using a burr until it bleeds: this step is described as being critical because it gives an optimal healing environment at the bone-labral junction which is anchored by a non-absorbable suture. According to Ok et al. (2012) double anchor sutures for SLAP type II lesions provide better restoration and stability.

In a study of patients over 45 years old, Abbot and Busconi (2009) declared that the treatment choice for SLAP type II lesions associated with rotator cuff tears was arthroscopic repair of the rotator cuff tear with subacromial decompression combined with debridement of the glenoid labrum. This gives better results compared to arthroscopic repair of the rotator cuff tear accompanied by repair of the glenoid labrum. In contrast Kanatli et al. (2011) reported that arthroscopic repair of SLAP type II lesions provided good results and can be negatively affected if it was associated with rotator cuff tears. A double-looped Cork-Screw anchor procedure has shown encouraging results (Kartus et al., 2004). In a study of patients suffering from a SLAP type II lesion treated by debridement of the detached glenoid labrum and abrading the glenoid rim until bleeds then fixed by staples, the outcome was excellent or good in 80% (n=8) of patients (Yoneda et al., 1991).

Comparison between different procedures in the treatment of SLAP type II lesions:

In a comparison of patients who either underwent arthroscopic suture anchor or arthroscopic transglenoidal suture repair for a SLAP type II lesion Maier et al. (2013) reported that arthroscopic suture anchor showed superior results. However, in a study of patients who either had an isolated SLAP type II repair or SLAP type II repair with acromioplasty, Coleman et al. (2007) reported that both surgeries gave satisfactory results, but the latter helped to prevent postoperative impingement of the glenohumeral joint. In a meta-analysis of patients who underwent either combined SLAP and rotator cuff repair or long head of biceps tenotomy and rotator cuff repair, the latter option was superior and gave better results in terms of function and range of movement (Kim et al., 2012). According to Enad and Kurtz (2007) in their treatment of patients either with isolated arthroscopic repair of SLAP type II lesion or combined treatment for SLAP type II lesion associated with extra-articular lesions, such as subacromial impingement syndromes and spinoglenoid cyst, arthroscopic repair of SLAP type II lesions associated with other lesions gave better results using biodegradable suture anchors.

Other SLAP lesions types:

DaSilva et al. (2008) state that a SLAP type III lesion is characterized by tears of the superior glenoid labrum with the long head of biceps tendon staying intact. They conducted two surgical options: the first was simple debridement of the torn aspect of the glenoid labrum only, and the second the same procedure as that described in the treatment of SLAP type II lesions. SLAP type IV lesions are characterized by bucket-handle tears of the superior labrum which extend to include the long head of biceps. Depending of the size and extent of the tear three surgical options are available. If the tear involves less than one third of the long head of biceps tendon, it can be treated by simple arthroscopic debridement and the bucket handle tear fixed similar to the SLAP type II procedure. If the tear includes more than one third, it can be treated by performing single free suture to the long head of biceps tendon while the labrum can be fixed in the same way as the SLAP type II procedure. Thirdly, by performing long head of biceps tenotomy or tenodesis followed by debridement or repair of the glenoid labrum. Seroyer et al. (2007) reported that arthroscopic capsulolabral reconstruction in athletic shoulders with a SLAP type VIII lesion showed reliable and effective results.

Management of Bankart lesions:

The outcome of the Bankart lesion is variable (Table 2.8.2). Bankart lesion management depends on many factors, such as the type of operation (open surgery or arthroscopic), associated lesions and the size of the lesion. Open Bankart repair with suture anchors associated with the capsular shift procedure was more effective in small Bankart lesions compared to large ones (Lai et al., 2006). Kamath et al. (2013) reported that two double loaded suture anchors were better or equal to three single loaded suture anchors because it needed fewer anchor holes in the glenoid bone, which could decrease the incidence of postsurgical glenoid fracture. In six patients Kim et al. (2009b) confirmed that arthroscopic three-point double row reconstruction of Bankart lesions was effective and provided stable fixation. In patients who underwent arthroscopic bony Bankart Bridge to treat their Bankart lesion with an average glenoid bone loss of 29% (n=14) Millett et al. (2013) observed that successful stability was achieved in 93%. Open Bankart repair has been used to restore anterior glenohumeral stability of 40 patients (20 with and 20 without glenoid bone): the Rowe was decreased in cases associated with any increase in the glenoid labrum defect; therefore, the glenoid bone defect was suggested to be fixed with the outcome of the operation being dependent on the size of the defect (Rhee and Lim, 2007).

4. Outcome of glenoid labrum lesions repair:

Outcome of SLAP lesions:

Table 2.8.1: Comparison between several studies in the outcome of SLAP lesion repairs

Study	No	Method	Results
Galano et al.(2010)	22	Suture anchor technique	90% return to sports
Morgan et al. (1998)	102	SLAP type II repair, Suture anchor technique	83% excellent outcomes
Yung et al. (2008)	16	Suture anchor technique	87.5% between good and excellent
Brockmeier et al. (2009)	47	Suture anchor technique	87.23% between good and excellent
Frank and Snow (2007)	18	Suture anchor technique	89% rate of satisfaction
Snyder et al. (1995)	140	Suture anchor technique	83% between good and excellent
Cohen et al. (2006)	39	Biodegradable tacks	69.23% between good and excellent
Samani et al. (2001)	25	Bioabsorbable tacks	68% return to their sport
Friel et al. (2010)	48	Suture anchor technique	54% return to their sport
Sayde et al. (2012)	506	Staples, suture anchor, bioabsorbable and tacks	63% return to their sport
Alpert et al. (2010)	52	Suture anchor technique	84% between satisfied to complete satisfied
Franceschi et al. (2008)	31	Suture anchor technique	100% between good and excellent
Mok and Wang (2012)	72	Biodegradable screw with one suture	94% were between good and excellent
Neri et al. (2010)	33	Suture anchor technique	96% were good- excellent score
Neuman et al. (2011)	30	Bioabsorbable suture anchor	84.1% returned to their sport
Oh et al. (2009)	97	Suture anchor technique	83.3% returned to their sports
Park et al. (2013)	24	Suture anchor technique	76% recovered and 50% returned to their sport
Provencher et al. (2013)	225	Suture anchor and vertical suture construction	Western Ontario Shoulder Instability 82%. Single Assessment Numeric Evaluation 85% American Shoulder and Elbow Surgeons 88%
Ricchetti et al. (2012)	58	Suture anchor technique	65% stable and no pain
Verma et al. (2007)	22	Suture anchor technique	47% returned to their work

Outcome of Bankart lesions operation:

Table 2.8.2: Comparison between several studies in the outcome of Bankart lesion repair

Study	No	Method	Results
Bioleau et al. (2012)	64	Neer modification of the open Bankart procedure	Average Row score 83%. Average Walch-Duplay score 83%. 56% returned to their sport
Carreira et al. (2006)	85	Arthroscopic repair using suture anchors	Average Row score 88% with 90% excellent – good and American Shoulder and Elbow Surgeons scoring index averaged 92%
Elmlund et al. (2009)	81	Arthroscopic Bankart repair using absorbable tacks	Average Row score 91%
Flinkkila et al. (2010)	170	Arthroscopic suture anchor repair	Oxford instability scores: 21 and subjective shoulder values: 84%
Jeong and Shin (2009)	6	Proud metallic suture anchor after Bankart repair	American Shoulder and Elbow Surgeons scoring index averaged 88%
Law et al. (2008)	38	Arthroscopic Bankart repair, using metallic suture anchors or soft tissue bio-absorbable anchors	95% of patients had excellent or good Rowe score
Marquardt et al. (2006)	18	Arthroscopic Bankart repair using bioabsorbable tacks	Rowe score was 90.3% with 83.3% were good - excellent
Ogawa et al. (2010)	163	Open Bankart procedure using suture anchor	95.2% stabilized glenohumeral joint
Voos et al. (2007)	30	Combined lesions of Bankart, SLAP and rotator cuff tear. Arthroscopic suture anchor and Suretac anchor.	American Shoulder and Elbow Surgeons scoring index averaged 94.3% with 90% were good – excellent. 77% returned to their sports

Chapter 3: Methods and Materials

One hundred and forty shoulders were harvested from formaldehyde-embalmed cadavers used for undergraduate teaching. The dissection procedure involved a number of stages.

The first stage:

The skin, superficial and deep fascia were removed from all over the shoulder area.

Anteriorly: The deltopectoral groove was cleaned and the cephalic vein identified, detached and reflected. The anterior part of deltoid was identified, detached from the clavicle and acromion and reflected laterally. Pectoralis major and minor were identified, cleaned, detached from their origins and reflected laterally to expose the brachial plexus and the brachial artery and its branches. The fibrous and fatty tissues located around and between the brachial plexus and its branches, the axillary artery and its branches, and the axillary vein and its tributaries, were carefully removed by blunt dissection. The brachial plexus was identified and then removed.

As the anterior circumflex humeral vessels passed from medial to lateral posterior to the short head of biceps brachii and coracobrachialis a fibrous fatty tissue attachment was observed between them. Therefore the short head of biceps brachii and coracobrachialis were detached from the coracoid process, carefully reflected distally and removed; blunt dissection was used to detach the anterior circumflex humeral vessels from the back of muscles. The long head of biceps brachii was left attached to preserve the actual course of the anterior circumflex humeral vessels.

The anterior circumflex humeral artery and its accompanying veins were blunt dissected from proximal to distally. As the vessels approached the surgical neck of the humerus, inferior and parallel to the inferior border of the subscapularis tendon and superior to the pectoralis major tendon, they were covered by thick fibrous fatty tissue, which was firmly attached to both the anterior circumflex humeral vessels and humerus; blunt dissection was carried using micro-dissection forceps, Teaser needle straight and small scissors in order to remove the thick fibrous tissue. During dissection the area became greasy and the anterior circumflex humeral vessels difficult to identify; gentle wiping with tissue, blowing cold air and waiting for some minutes allowed the oily fluid to dry out and the blood vessels to re-distend and become more obvious.

As the anterior circumflex humeral vessels passed deep to the long head of biceps brachii to ramify in deltoid, they were firmly adherent to the underlying bone and the long head of biceps; gentle blunt dissection was undertaken to release the long head of biceps and reflect it proximally. The ascending branch of the anterior circumflex humeral artery which passed underneath the tendon was also cleaned and traced. Following the same protocol of wiping, blowing cold air and waiting a few minutes the anterior circumflex humeral artery and accompanying veins with their branches and tributaries were cleaned. In order to trace the branches and tributaries of the anterior circumflex humeral vessels subscapularis, teres major, latissimus dorsi, and pectoralis major and minor were removed. A record of the gross dissection and photographs of the anterior circumflex humeral artery and its branches and the anterior circumflex humeral veins and their tributaries were taken (Figures 3.1 to 3.5).

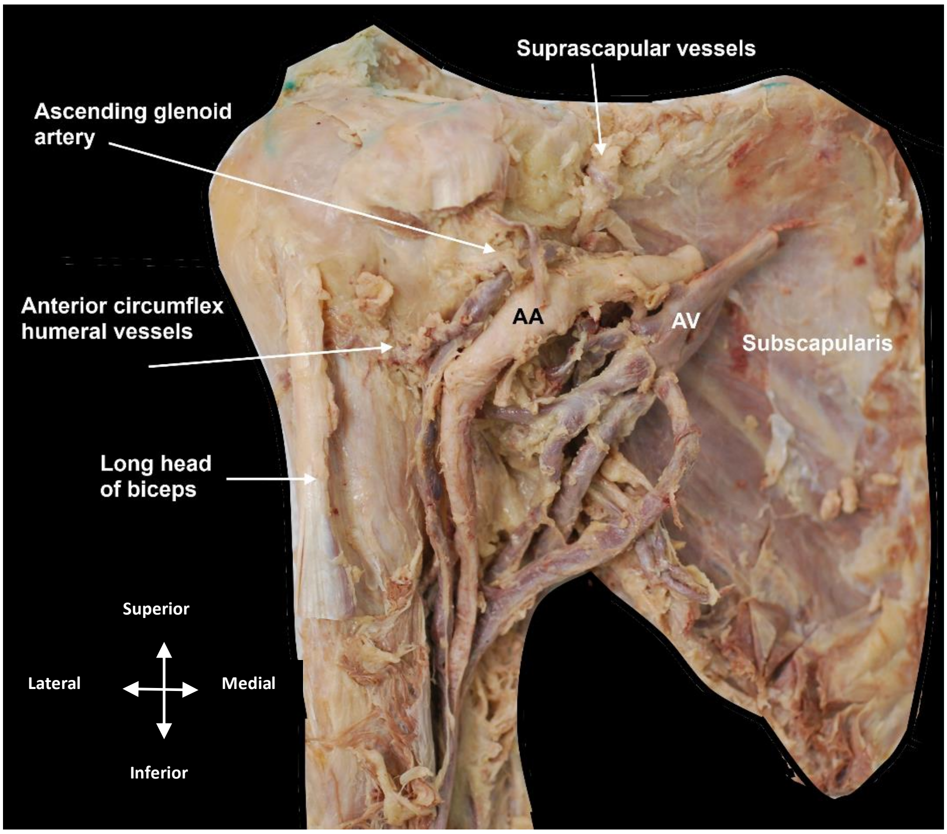


Figure 3.1: Anterior view of the right shoulder showing dissection process; AA: axillary artery, AV: axillary vein.

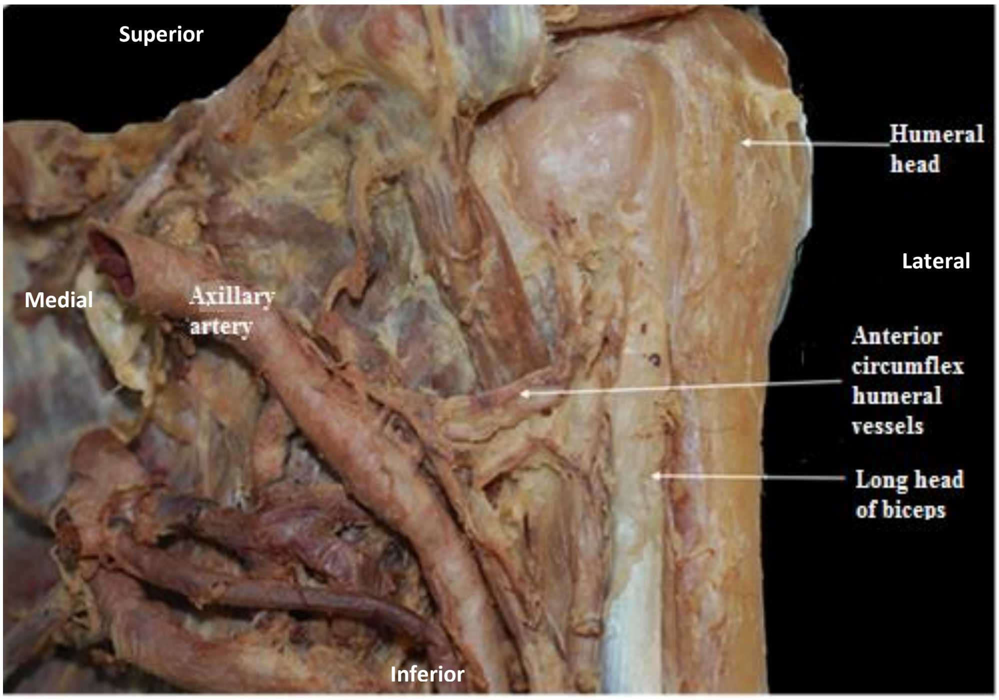


Figure 3.2: Anterior view of the left shoulder showing the fibrous tissue around the anterior circumflex humeral vessels and adherent to biceps and humerus.

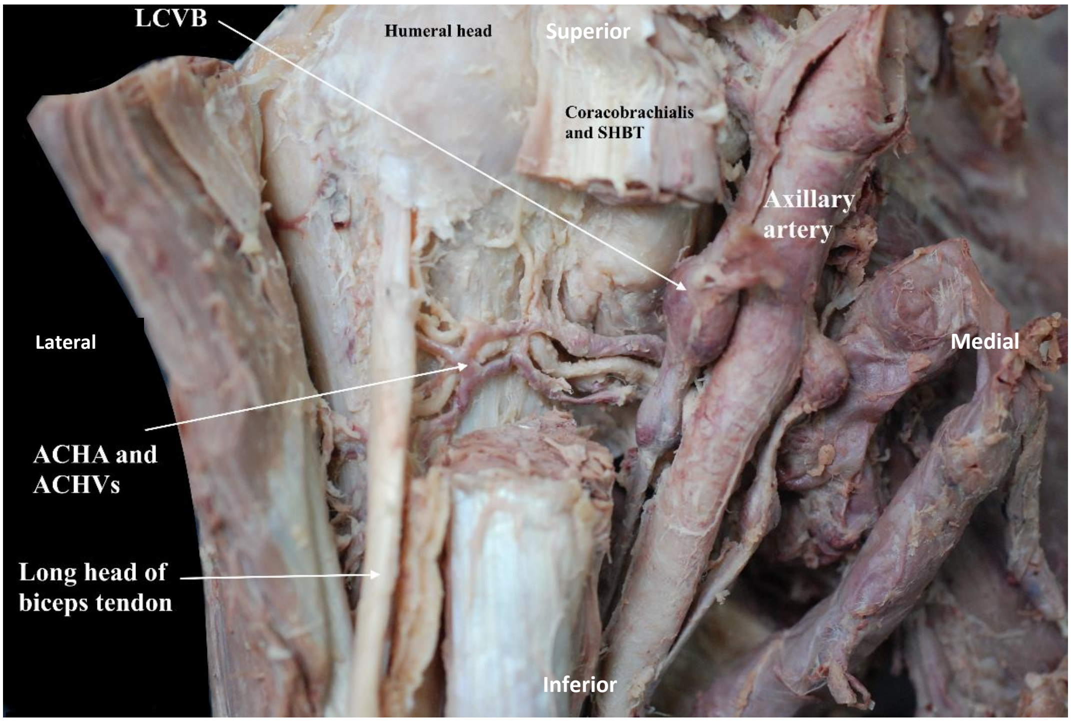


Figure 3.3: Anterior view of the left shoulder showing dissection of the anterior circumflex humeral artery and veins (ACHA, ACHVs); LCVB: lateral concomitant vein of the brachial artery, SHBT: short head of biceps tendon.

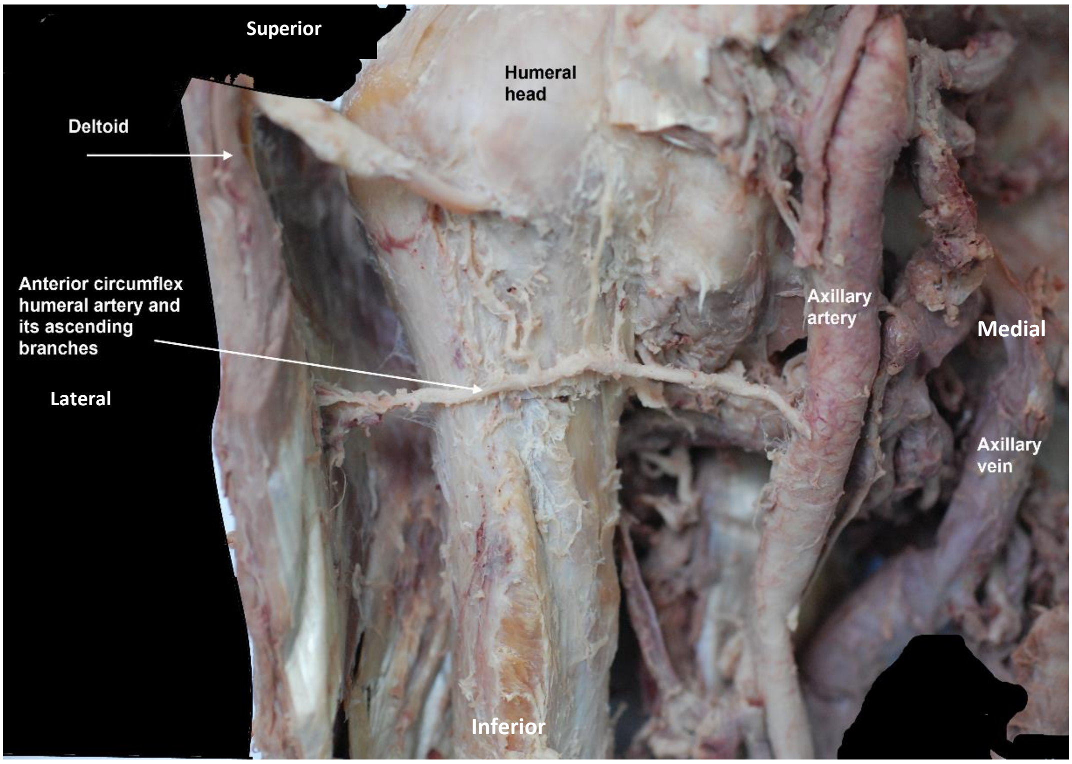


Figure 3.4: Anterior view of the left shoulder showing branches of the anterior circumflex humeral artery.

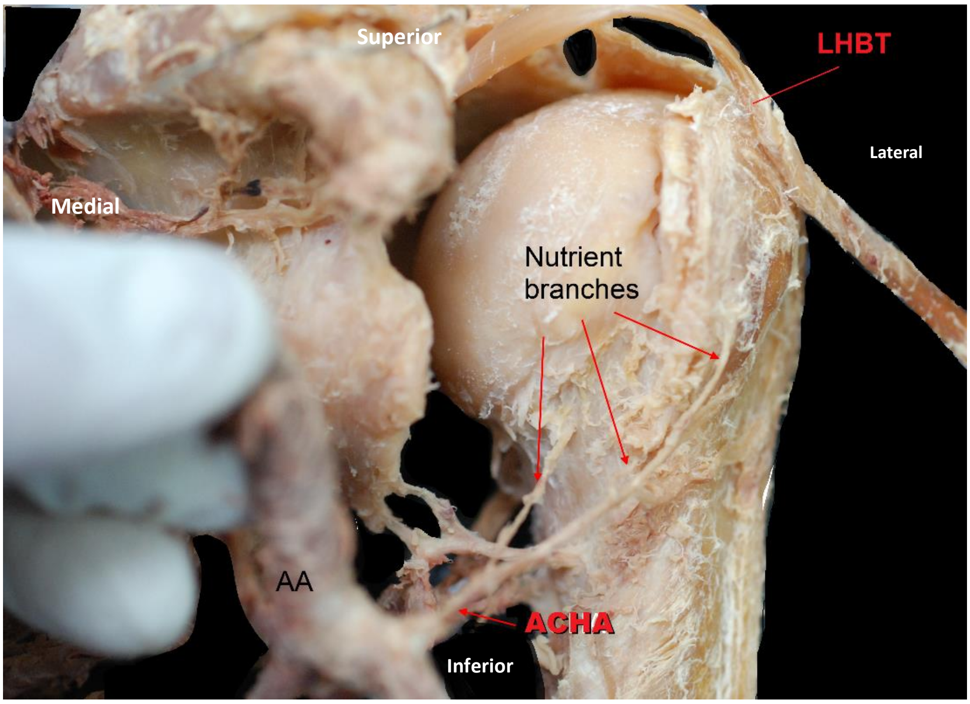


Figure 3.5: Anterior view of the left shoulder showing the nutrient branches of the anterior circumflex humeral artery (ACHA). LHBT: long head of biceps tendon.

Superiorly: using blunt dissection trapezius was removed and the proximal attachment of the middle and posterior parts of deltoid from the coracoid process and posterior aspect of the spine of the scapula were released, following which the clavicle was removed. In order to trace the suprascapular artery, a mass of fatty fibrous tissue on supraspinatus was removed and a lateral incision was made in the tendon near its insertion and was gently reflected medially. The suprascapular vessels and nerve were found lying directly on the bone and covered by fibrous fatty tissue separating them from supraspinatus. A superficial incision was made through these to facilitate the careful removal of both tissues. The suprascapular neurovascular bundle was cleaned, identified and recorded (Figures 3.6 to 3.8).

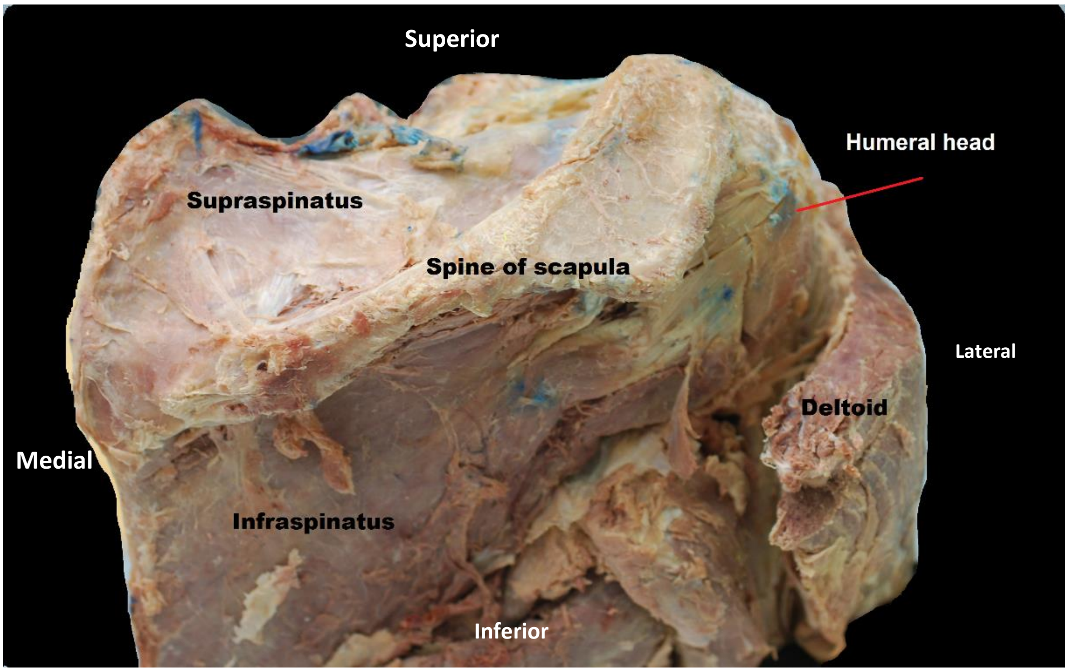


Figure 3.6: Posterior view of the scapula showing supraspinatus, infraspinatus, deltoid and the humeral head.

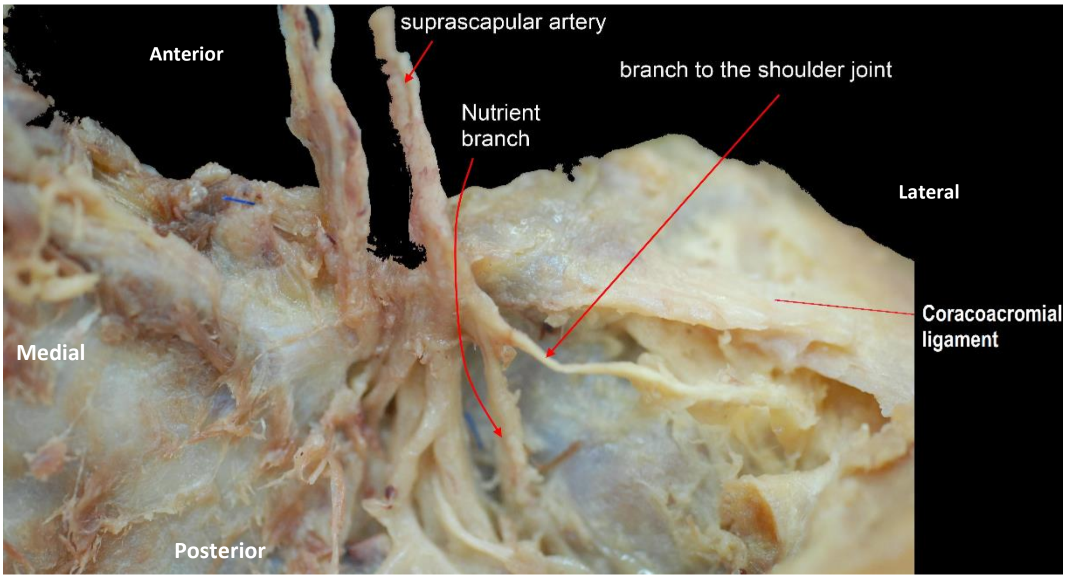


Figure 3.7: Superior view of the supraspinous fossa showing nutrient and articular branches of the suprascapular artery.

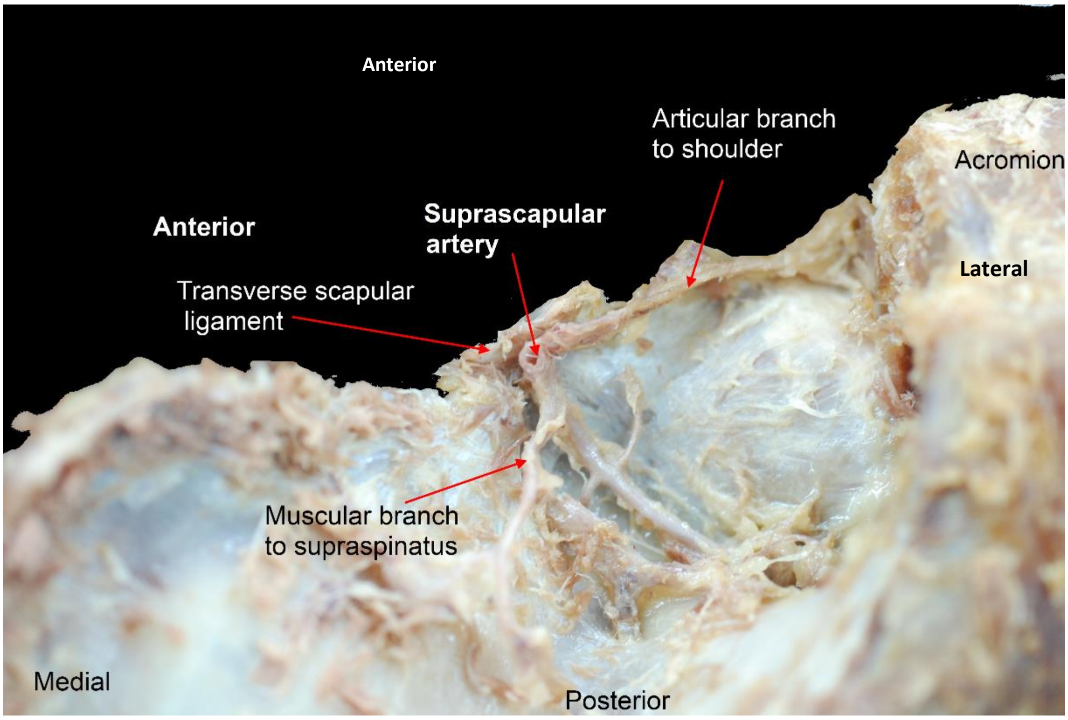


Figure 3.8: Supraspinous fossa showing muscular and articular branches of the suprascapular artery.

Posteriorly: Infraspinatus and teres minor were sectioned near their insertion and reflected medially. Thick bands of fibrous fatty tissue filled the spinoglenoid notch; an incision was made and the tissues separated. A recorded dissection was accomplished tracing the branches of the suprascapular vessels in the infraspinous fossae (Figure 3.9). **Inferiorly**: in order to have better view the upper limb was abducted at the glenohumeral joint. Teres major and the lateral superior aspect of subscapularis were removed. The posterior circumflex humeral artery and its branches, the accompanying veins and the axillary nerve were cleaned and identified as they passed around the surgical neck of the humerus inferior to the shoulder joint. The lateral head of triceps was removed and the long head of triceps cleaned. All branches and tributaries of the posterior circumflex humeral vessels were recorded and photographed (Figures 3.10 to 3.15).

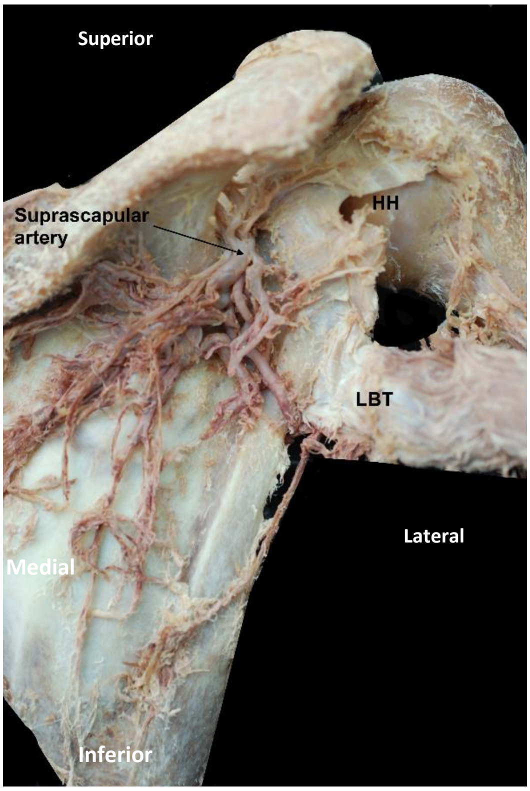


Figure 3.9: Posterior view of the right scapula showing branches of the suprascapular artery. LHT: long head of triceps, HH: humeral head.

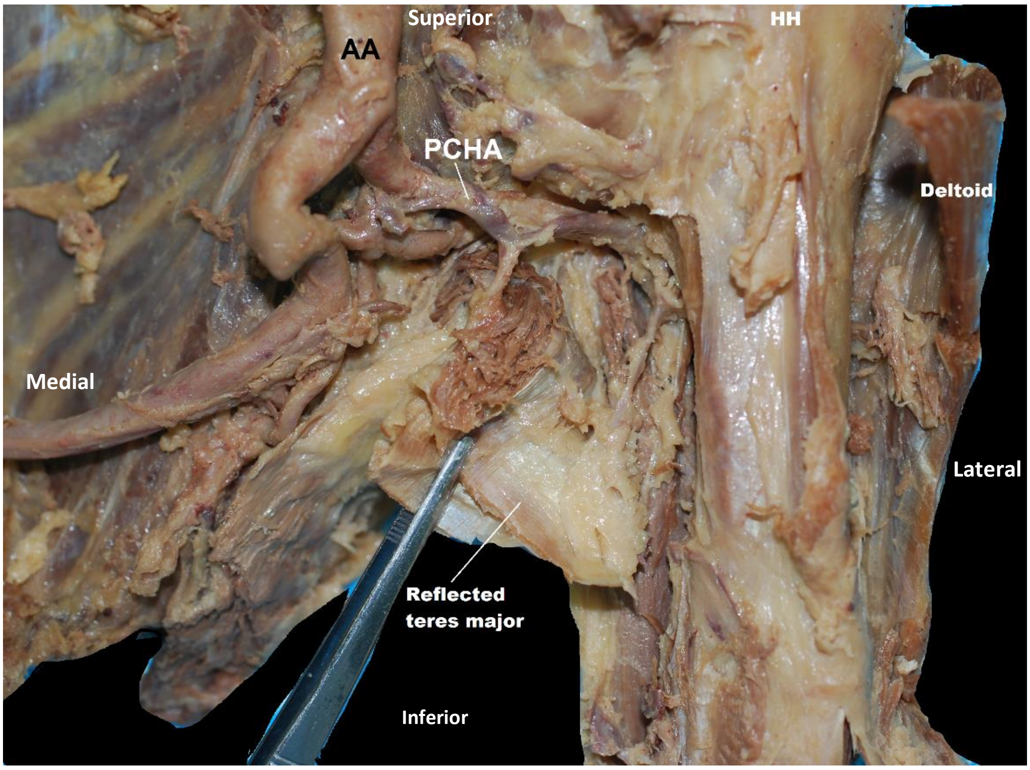


Figure 3.10: Anterior view of the left shoulder showing dissection of the inferior aspect of the glenohumeral joint. PCHA: posterior circumflex humeral artery, HH: humeral head, AA: axillary artery.

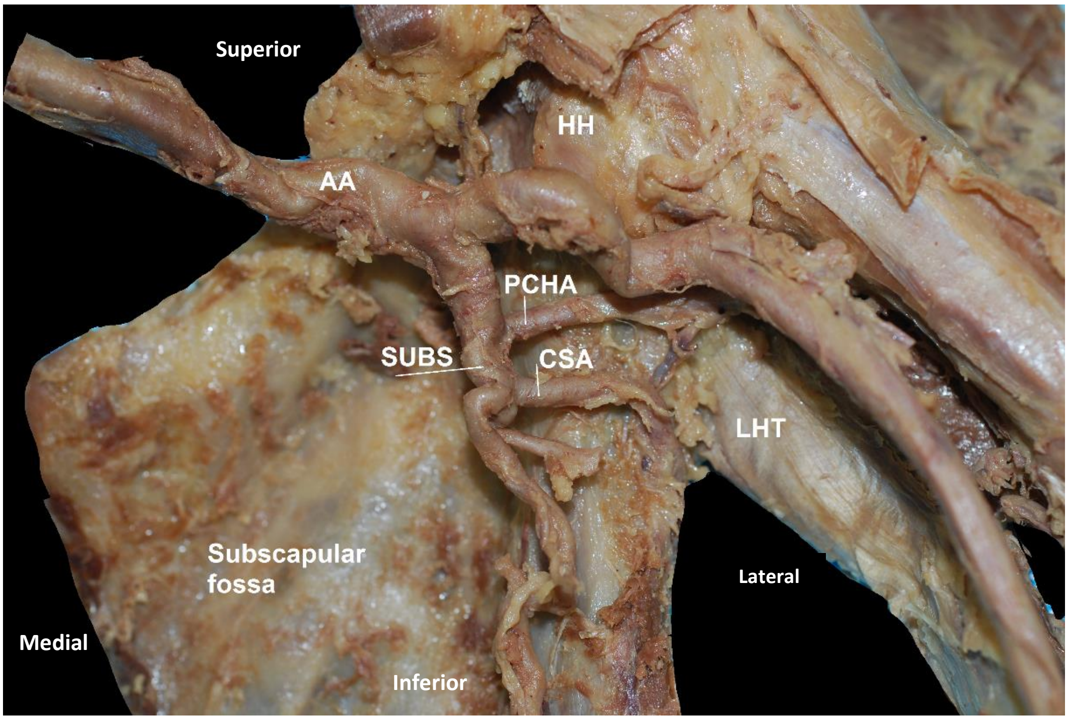


Figure 3.11: Anterior view of the left shoulder showing dissection of the inferior aspect of the glenohumeral joint. PCHA: posterior circumflex humeral artery, HH: humeral head. CSA: circumflex scapular artery, SUBS: subscapular artery, AA: axillary artery, LHT: long head of triceps.

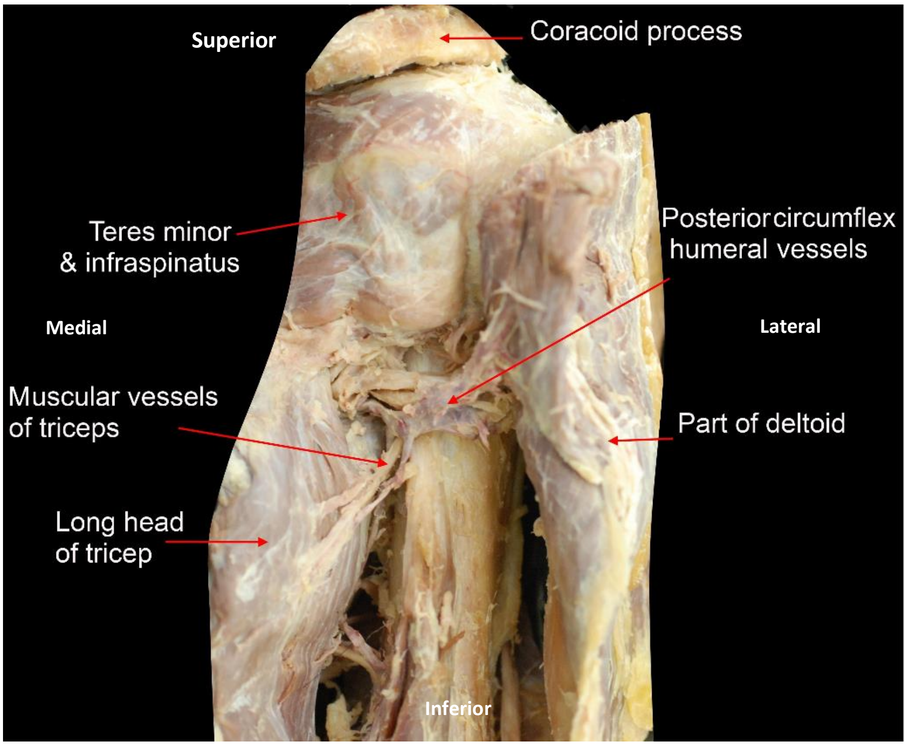


Figure 3.12: Posterior view of the right shoulder showing the posterior circumflex humeral vessels.

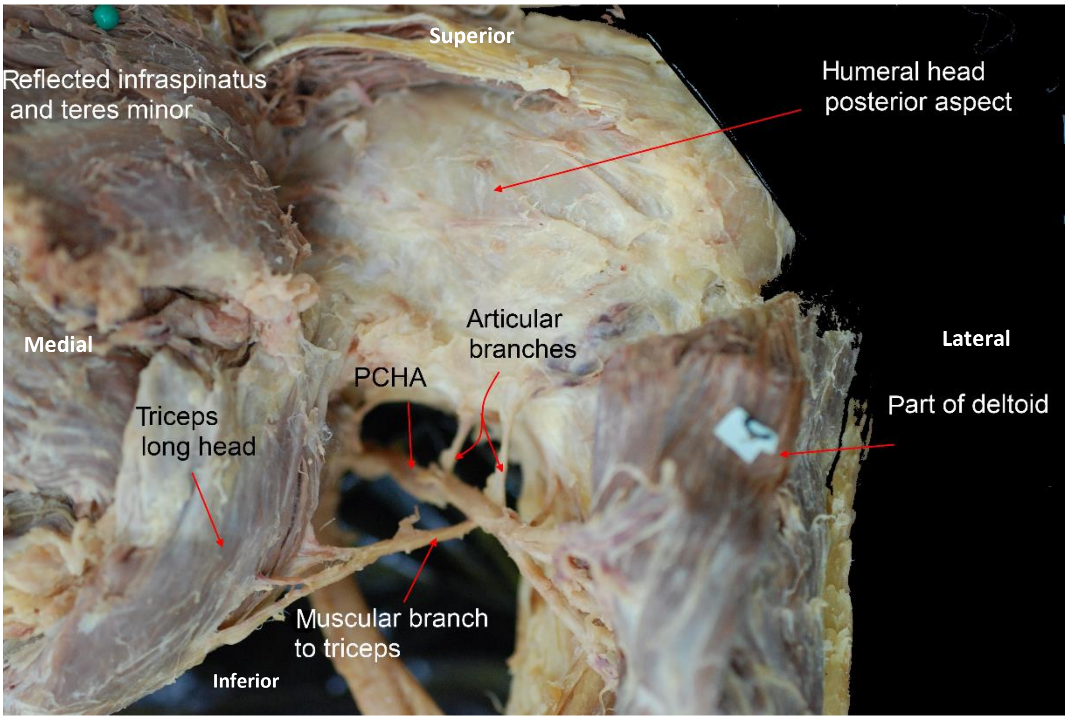


Figure 3.13: Posterior view of the right shoulder showing branches of the posterior circumflex humeral artery (PCHA).

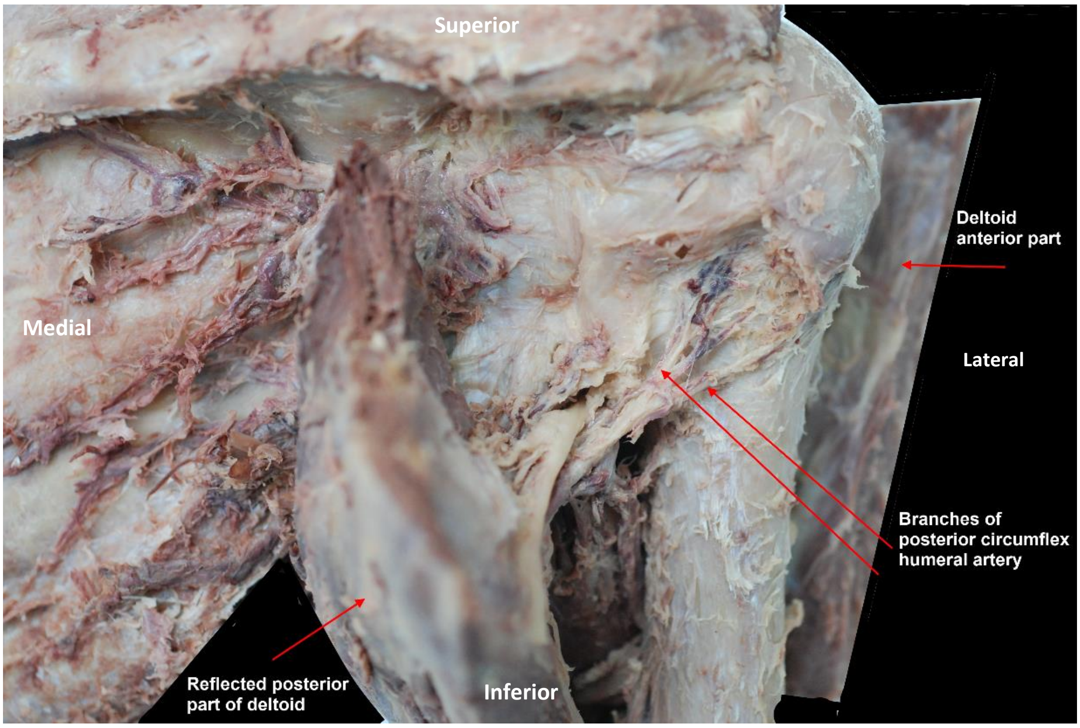


Figure 3.14: Posterior view of the right shoulder showing branches of the posterior circumflex humeral artery.

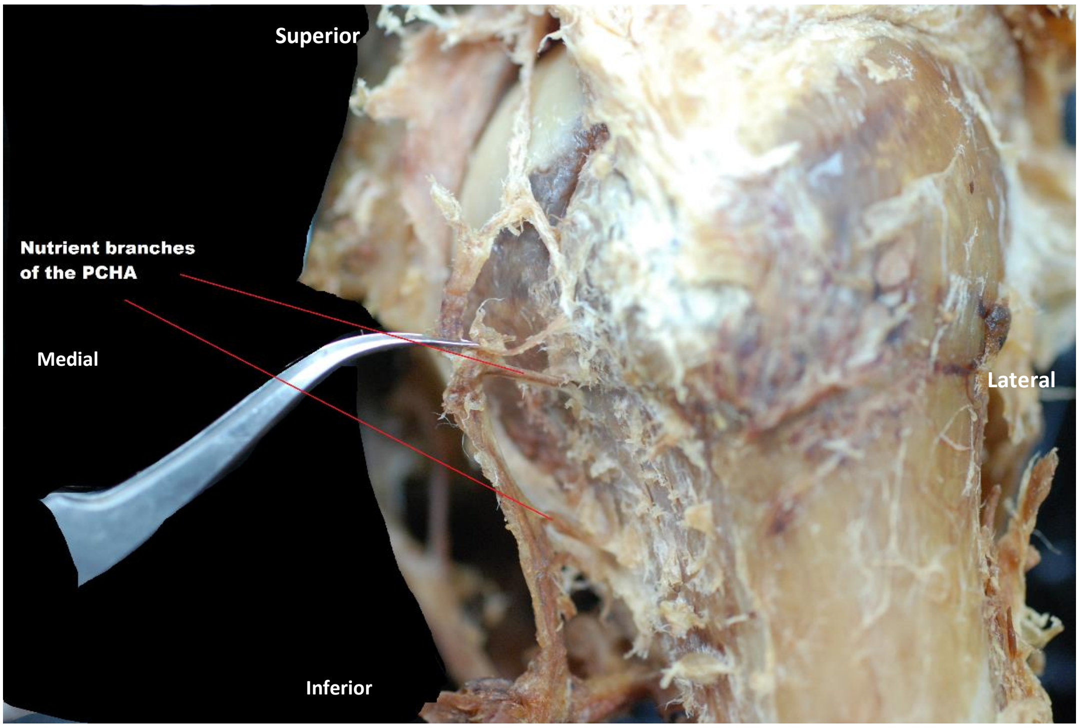


Figure 3.15: Posterolateral view showing nutrient branches of the posterior circumflex humeral artery (PCHA) supplying the anatomical and surgical necks of the humerus.

Anteriorly: a direct branch from the second part of the axillary artery (ascending glenoid artery) (Figures 3.16 to 3.18) passing under the coracoid process towards the anterosuperior and superior aspects of the shoulder joint was dissected and cleaned from proximal to distal. In order to have a clear view and trace the arterial branches careful sectioning of the subscapularis tendon near its insertion was made and the muscle reflected medially. Pulling the head of the humerus inferiorly increased the space under the coracoacromial arch facilitating the dissection. A record of the direct branch and its branches was taken.

The subscapular artery and its branches and the subscapular vein and its tributaries were identified, cleaned and recorded from proximal to distal. The circumflex scapular artery and vein passed posteriorly on the lateral border of the scapula, inferior to the origin of the long head of triceps and then coursed inferiorly between teres minor anteriorly and major posteriorly ramifying in the infraspinous fossa. All the circumflex scapular vessels with their branches and tributaries were traced, cleaned and recorded (Figures 3.19 to 3.21).

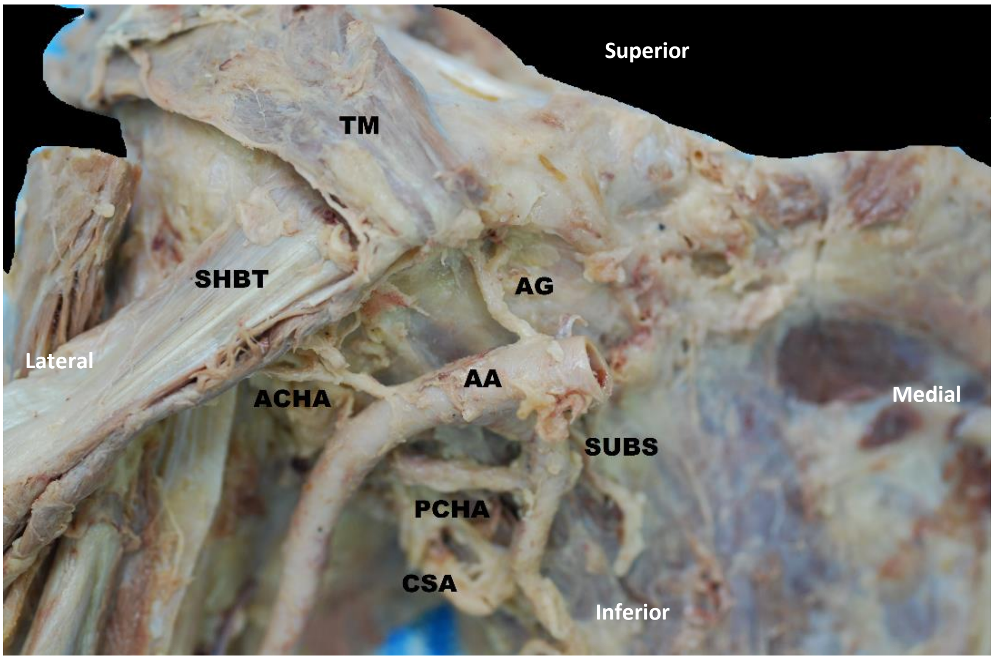


Figure 3.16: Anterior view of the right shoulder showing the ascending glenoid artery (AG) arising from the axillary artery (AA). SUBS: subscapular; PCHA: posterior circumflex humeral artery; CSA: circumflex scapular artery; ACHA: anterior circumflex humeral artery, TM: teres minor (reflected); SHBT: short head biceps tendon.

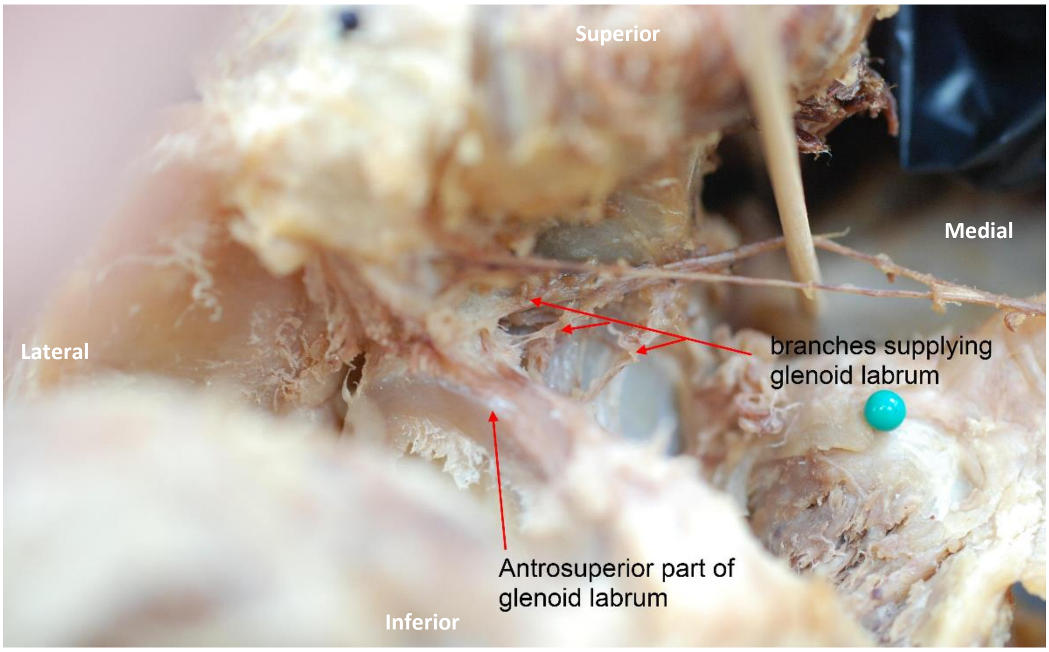


Figure 3.17: Anterior view of the right shoulder showing branches of the ascending glenoid artery supplying the glenoid labrum.

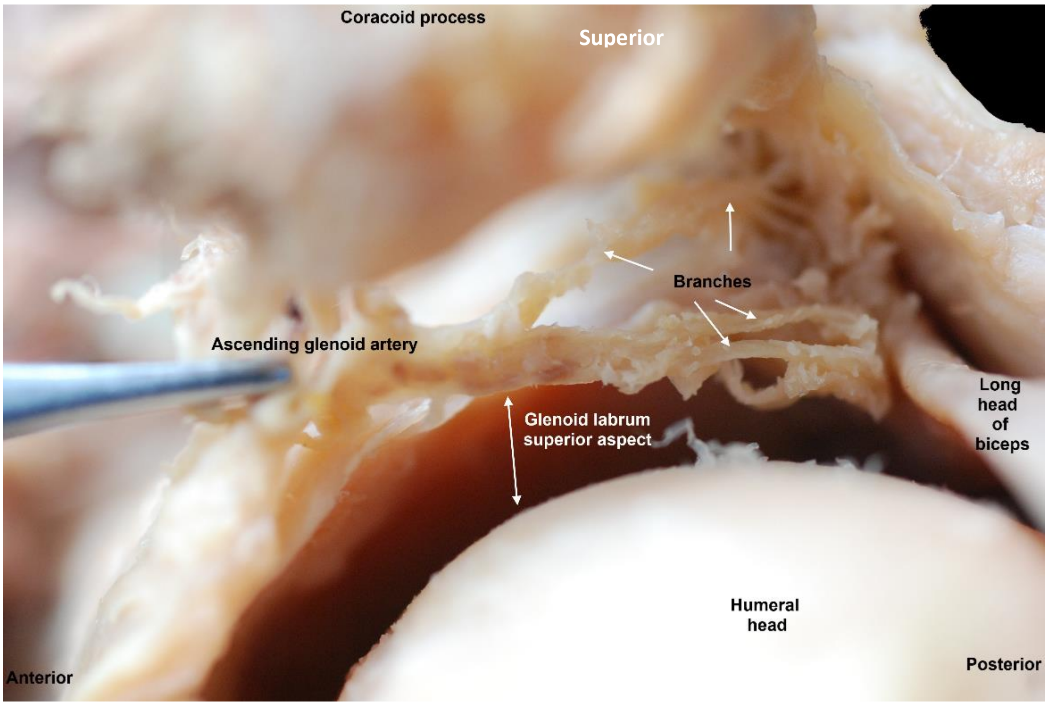


Figure 3.18: Lateral view of the right shoulder showing branches of the ascending glenoid artery (AG). LHBT: long head of biceps tendon; HH: humeral head.

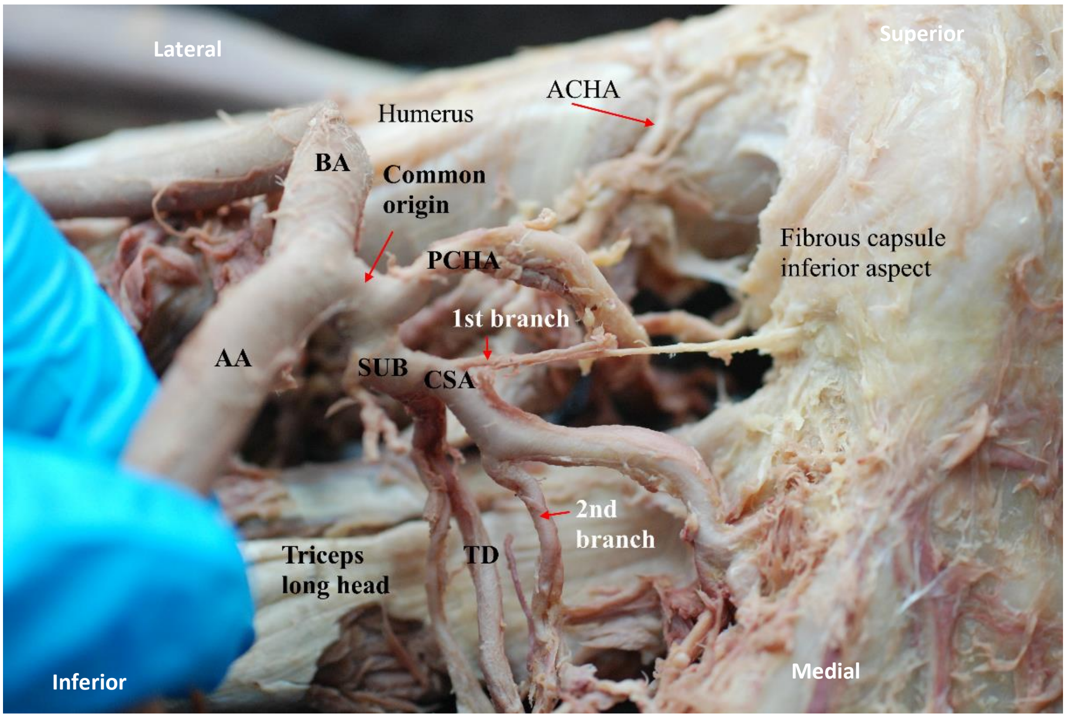


Figure 3.19: Showing the inferior glenoid artery (1st branch) arising from the circumflex scapular artery (CSA). Reflected axillary artery (AA); BA: brachial artery; ACHA: anterior circumflex humeral artery; PCHA: posterior circumflex humeral artery.

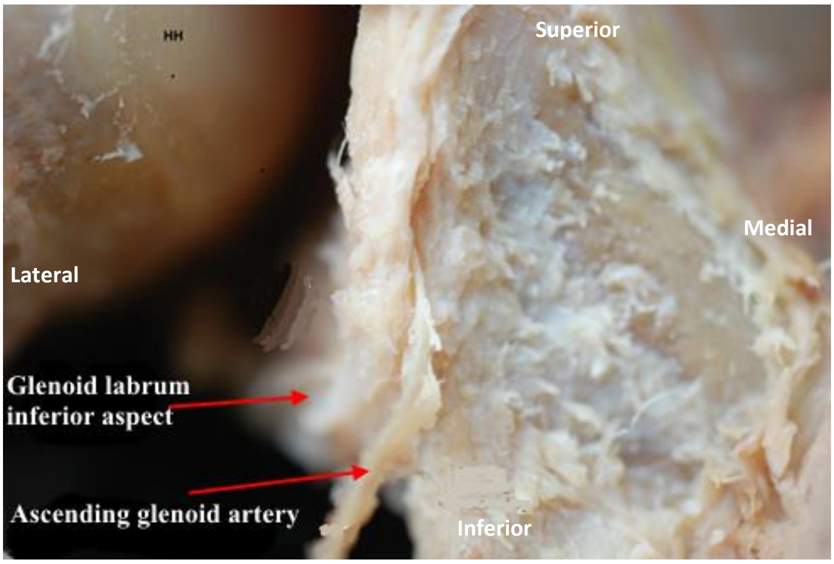


Figure 3.20: Inferior view of the right shoulder showing the inferior glenoid artery passing through the inferior aspect of the glenoid labrum. HH: humeral head.

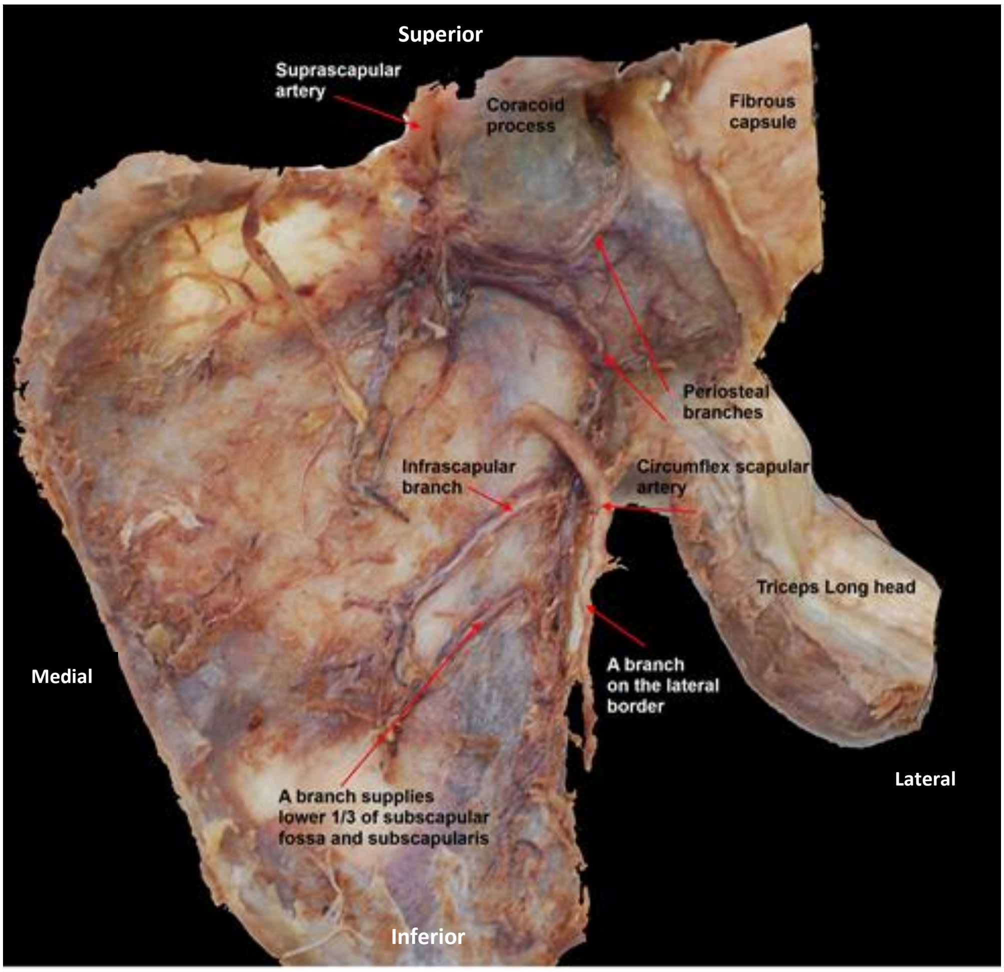


Figure 3.21: Left scapula showing branches of the circumflex scapular artery

Using coloured silicone

Coloured silicone (mix ratio 100 silicone:10 scilicone catalyst by weight) has been used: it has low viscosity to assure perfusion of even the smallest vessels and was harden within a reasonable time, but retain sufficient elasticity and resistance to withstand tearing off the delicate vessels during subsequent dissection.

Injection of the coloured silicone through branches of the axillary artery was performed in five selected shoulders, left for 48 hours then dissected following the above procedure and technique (Figure 3.22). Records were taken of all blood vessels found. The shoulders were then frozen at - 86 ℃ for 24 hours and cut using an electric band saw; some shoulders were cut from anterior to posterior passing through the head of the humerus, the glenoid fossa and glenoid labrum with the fibrous capsule attached, whereas others were cut from superior to inferior passing perpendicular to the glenoid fossa. Microdissection was performed under a microscope to trace and identify all blood vessels heading to supply the glenoid labrum (Figure 3.24): all blood vessels identified were photographed and recorded.

Using blue and green acrylic paint:

Acrylic paint is a water-soluble paint and contains pigment suspended in acrylic polymer emulsion, but becomes water-resistant when dry: its viscocity is lower than the silicone enabling it to pass into micro-blood vessels, but does not harden faster. Injection of the axillary artery with acrylic paint in five shoulders was undertaken and the shoulders were left for 48 hours then dissected following the above procedure and technique (Figure 3.23): all blood vessels and their branches were recorded. The shoulders were frozen and microdissection undertaken to be able to trace the course of the smaller blood vessels. All details of the branches of the blood vessels were recorded.

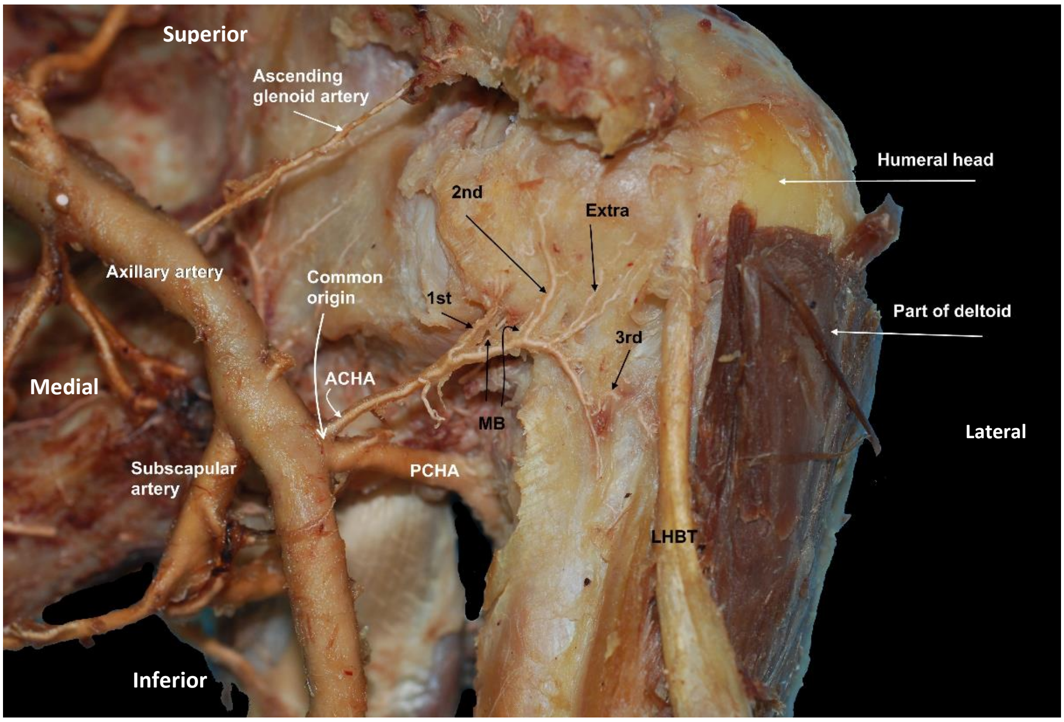


Figure 3.22: Anterior view of the left shoulder showing branches of the axillary artery filled with coloured silicone. PCHA: posterior circumflex humeral artery, ACHA: anterior circumflex humeral artery; LHBT: long head of biceps tendon.

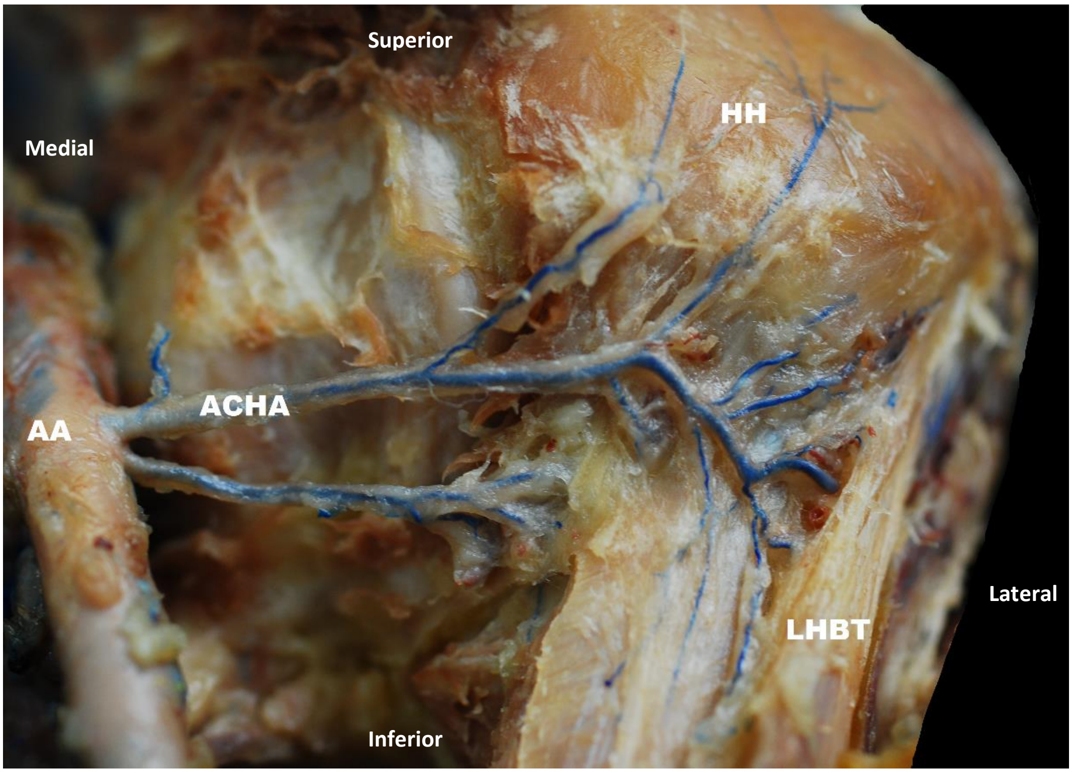
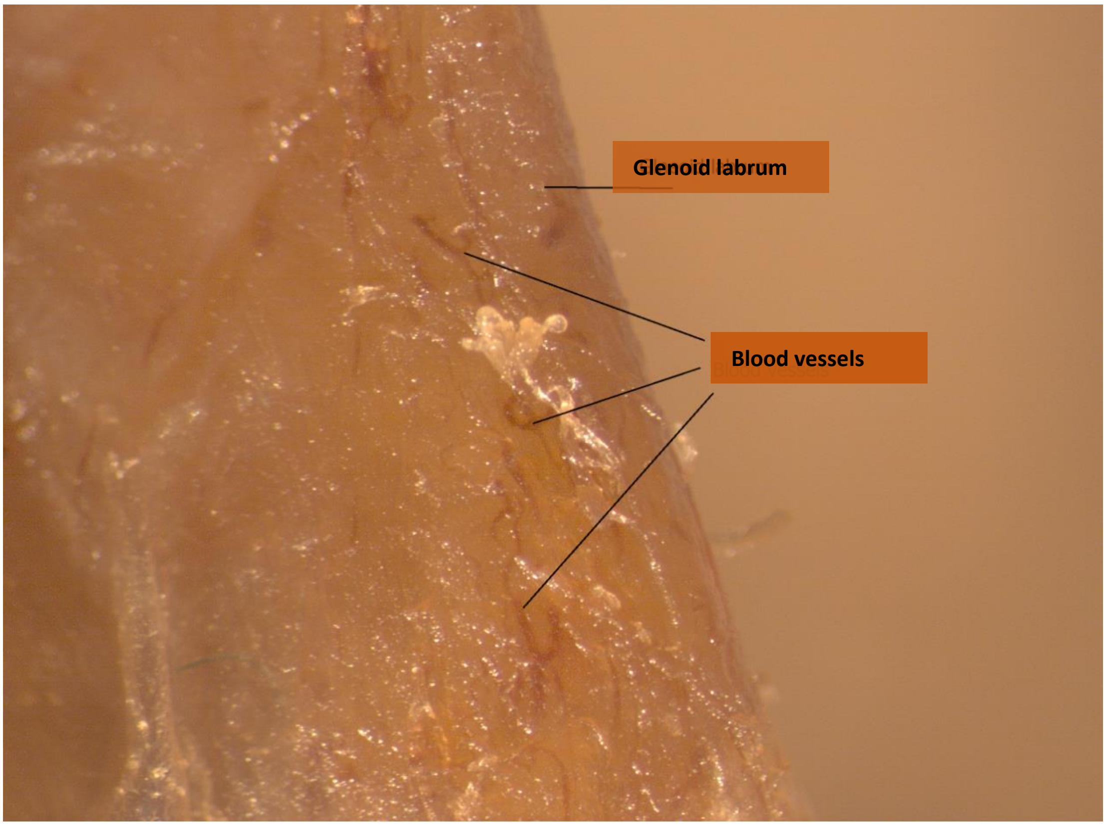


Figure 3.23: Anterior view of the left shoulder showing the axillary artery and its branches filled with blue water soluble acrylic paint. ACHA: anterior circumflex humeral artery.

Microdissection of the glenoid labrum:

Samples of the glenoid labrum were randomly taken from different shoulders and different regions. The glenoid labrum with some of the fibrous capsule attached was cut perpendicularly and microdissection undertaken. The blood vessels found were photographed and recorded (Figure 3.24).



A

B

Figure 3.24: Microdissection of the glenoid labrum showing (A) blood vessels inside the posterior glenoid labrum, (B) blood vessels inside the posterior glenoid labrum in transverse section.

The second stage:

A cut was made through the lateral part of the posterior aspect of the fibrous capsule of the shoulder joint and posterior dislocation of the humeral head was performed following which the long head of biceps brachii was released from the fibrous capsule superiorly. Observation of the interior anterior aspect of the fibrous capsule was done to identify and distinguish the glenohumeral ligaments. In order to have a better view of the glenohumeral ligaments lateral stretching of the fibrous capsule with some degree of humeral flexion was helpful. Distal release of the superior, anterior and inferior aspects of the fibrous capsule was undertaken. The following structures were examined and recorded.

1. Glenohumeral ligaments: site of origin and, using digital callipers, the thickness of the superior, middle and inferior glenohumeral ligaments recorded.

2. Long head of biceps brachii: mode of attachment and direction of fibres and by referring to Vangsness et al. (1994) classification was undertaken (Figure 3.25):

Type I: biceps attaches to the posterior part of the glenoid labrum

Type II: biceps attaches mostly to the posterior part of the glenoid labrum with a small contribution to the anterior part.

Type III: equal distribution between anterior and posterior parts of the glenoid labrum.

Type IV: biceps attaches mostly anterior with some contribution to the posterior part.

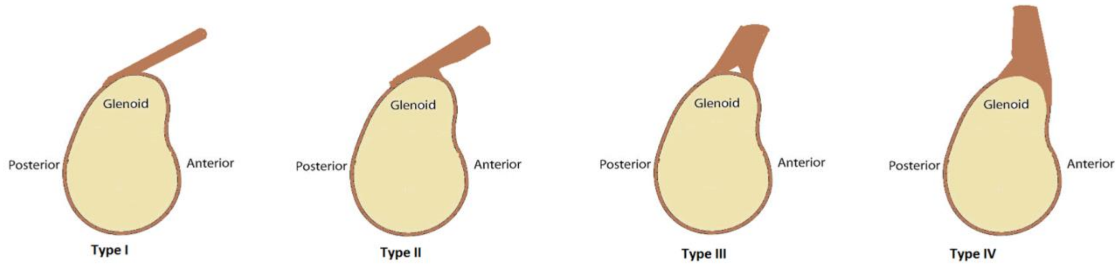


Figure (3.25): Classification of the long head of biceps attachment (adapted from Vangsness et al., 1994)

3. Glenoid labrum: general appearance, mode of attachment, consistency, thickness, depth (Figure 3.26).

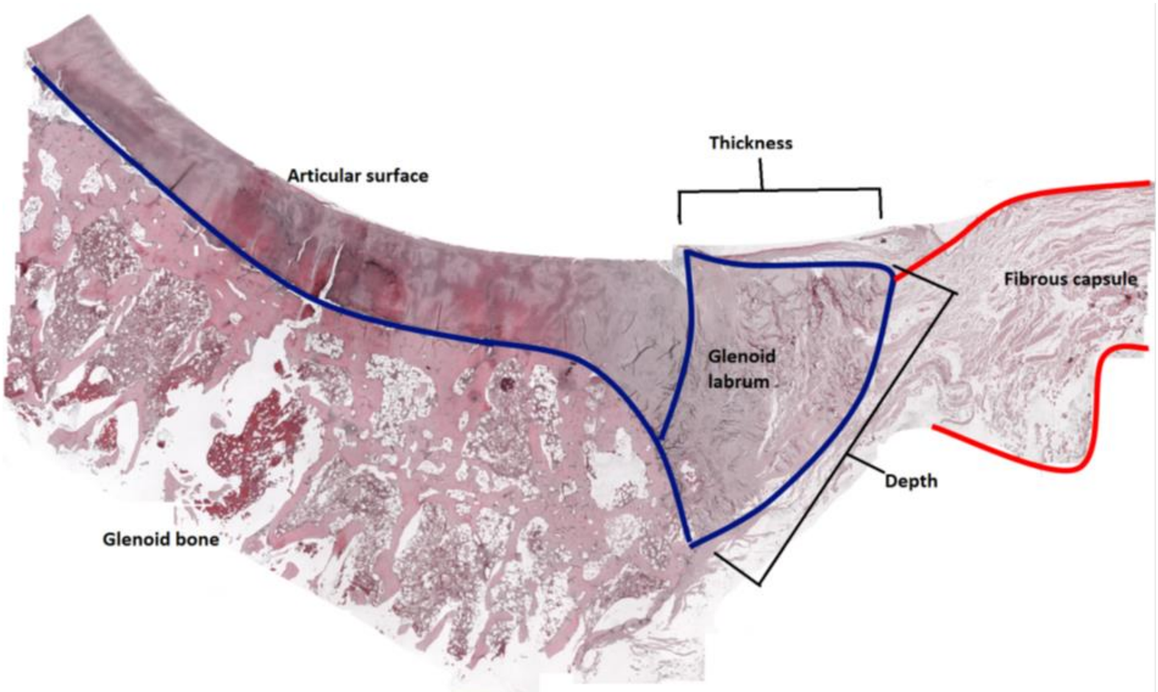


Figure 3.26: The thickness and the depth of the glenoid labrum.

4. Sublabral foramen

5. Sublabral recess: referring to De Maeseneer et al. (2000) classification (Figure 3.27):

Type I: firm attachment to the glenoid.

Type II: a small recess can be identified between the glenoid labrum and the glenoid.

Type III: a deep recess is present between the glenoid labrum and the glenoid sufficient to allow the insertion of a probe.

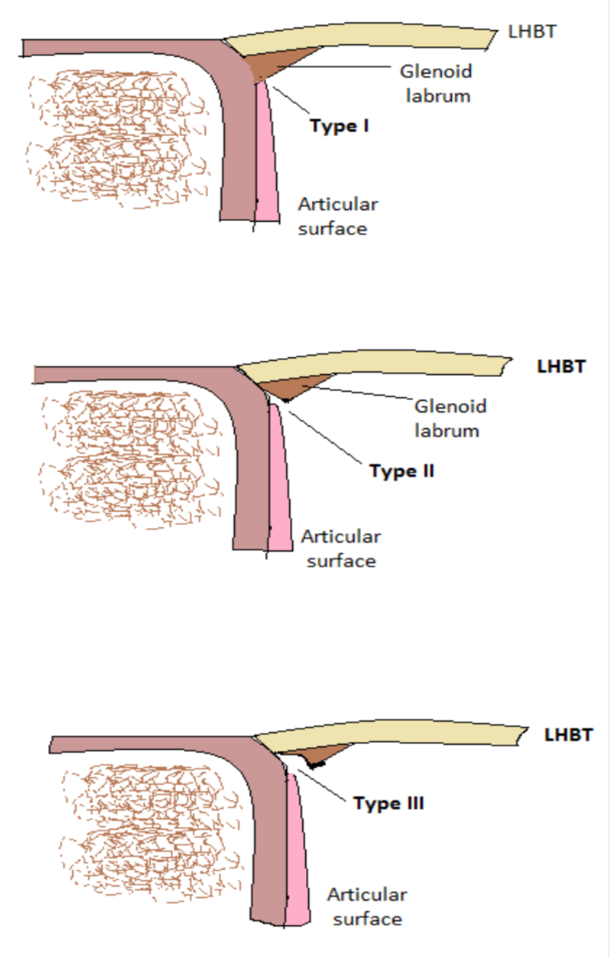


Figure 3.27: Classification of the sublabral recess (adapted from De Maeseneer et al., 2000).

5. Buford complex (Figure 3.28).

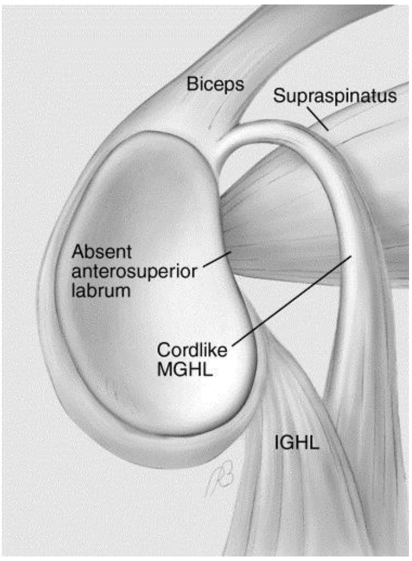


Figure 3.28: Buford complex (Powell et al., 2004)

6. Glenoid fossa:

A: Shape (Figure 3.29)

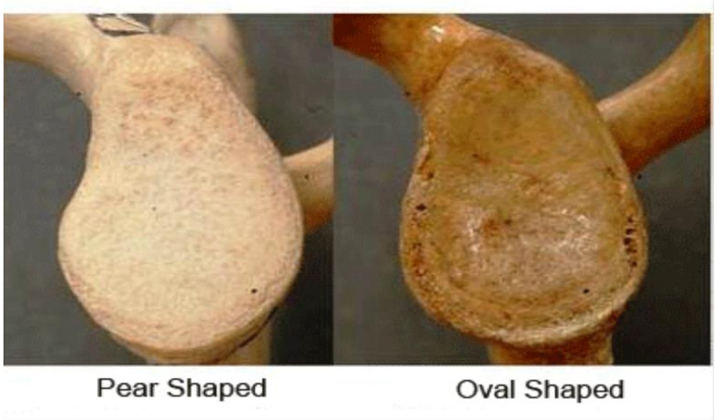


Figure (3.29): Shape of the glenoid fossa

B: Length, width and length at the highest width with the glenoid labrum attached (Figure 3.30).

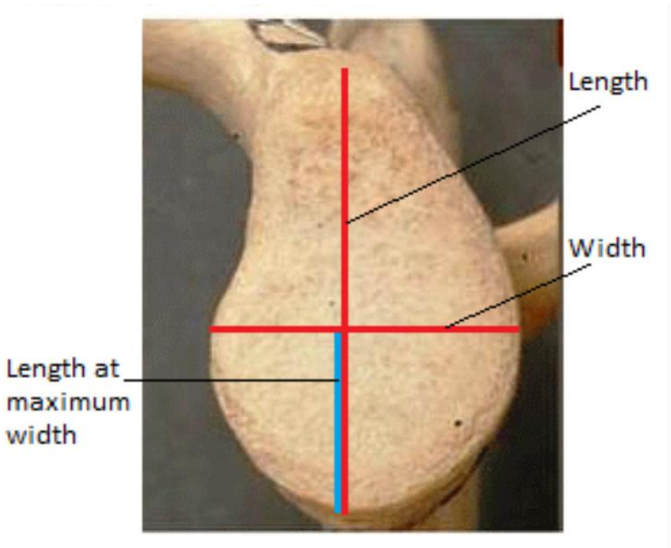


Figure (3.30): Measurement of the length, width and length of the glenoid fossa at the greatest width

C: Types of glenoid notch (Figure 3.31).

Figure 3.31: Types of glenoid notch.

D: Bare sport of the glenoid (Figure 3.32)

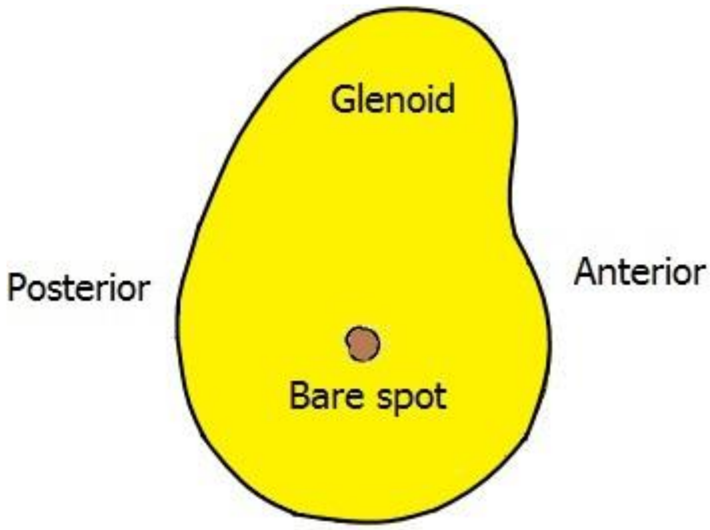


Figure 3.32: Bare spot

7: Attachment of the long head of triceps (width, superior and inferior thickness) (Figure 3.33).

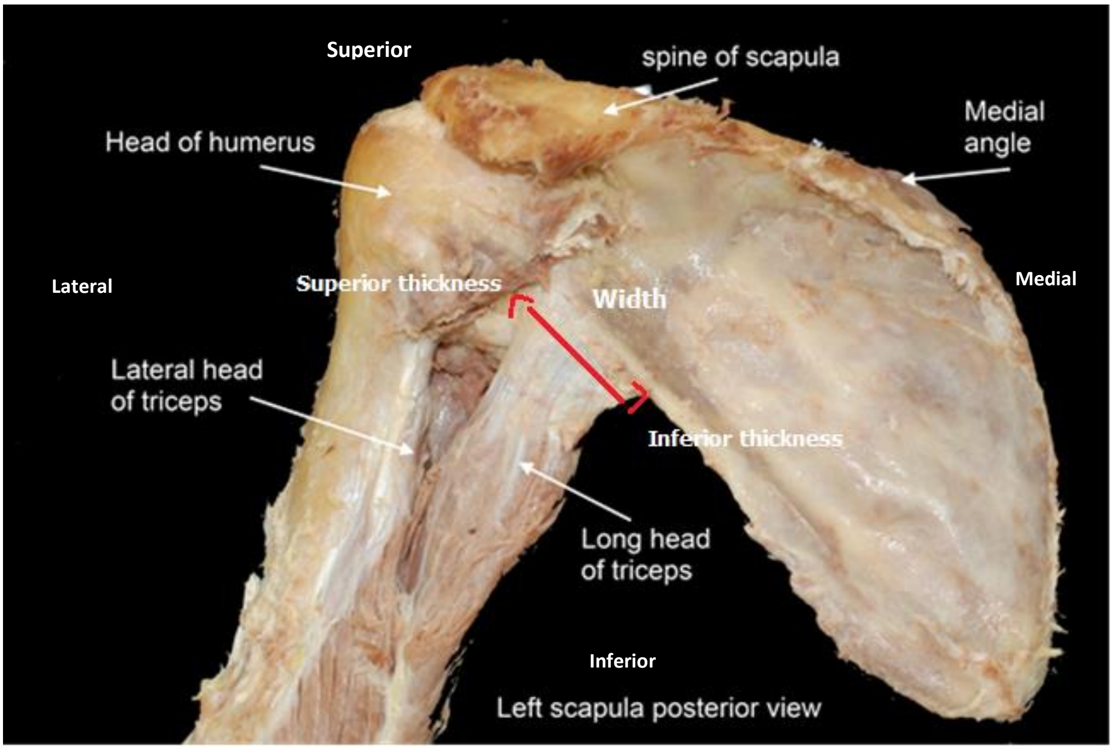


Figure 3.31: Measurement of the width and superior and inferior thickness of the long head of triceps brachii.

8. Attachment of the fibrous capsule to the glenoid labrum and scapula.

The third stage: histology

Procedure 1:

Decalcification:

Decalcification is the removal of the calcified component of bone tissue so that the remainder can be processed, cut and stained using the same techniques which would be applied to paraffin sections of soft tissues. A cut was made at the glenoid neck in four shoulders with the glenoid labrum and fibrous capsule attached. Sections were decalcified in a hydrochloric acid containing decalcifier for four months or a rapid decalcifier (formic acid, 10% in distilled water) for 48 hours, washed in phosphate buffered saline (PBS) and embedded in paraffin using standard techniques. Sections (10 - 20µm) were cut through the whole thickness from the centre of the glenoid fossa perpendicular to the glenoid labrum at 12 radii corresponding to a clock face superimposed on the glenoid. The outcome was a piece of tissue triangular in shape with the glenoid labrum and fibrous capsule attached to the periphery. Decalcification was done on a few shoulders only.

Ten shoulders were randomly chosen from five cadavers (5 right, 5 left). Each glenoid labrum was cut (similar to the above procedure) into twelve pieces (each piece corresponding to an hour on a clock face superimposed on the glenoid) using a sharp blade. The labrum was separated from the underlying glenoid bone with some part of the fibrous capsule remaining attached.

Tissue processing and embedding:

To prepare a tissue for embedding it needs to be infiltrated with paraffin. The procedure undertaken is shown in Appendix 2 Table 1. Ten micrometre sections were cut and put on slides. Different types of slides were used: plain frosted edge slides for eosin and haematoxylin and for silver nitrate staining; electrostatic and polylysine coated slides for immunohistochemistry. Following sectioning, slides were placed in an oven overnight at 58^0 to promote section adhesion. Staining with haematoxylin and eosin was carried as in shown in Appendix 2 Table 2.

Silver nitrate protocol

Gless-Marsland modification

Axons were stained using a silver nitrate protocol (Gless-Marsland modification). The tissue should be fixed in formalin-saline or natural buffered formalin solution and the paraffin sections should be cut at 6 – 8 micrometres thickness (Disbery and Rack, 1970). For the protocol of the procedure see Appendix 2.

Immunohistochemistry

I: Anti-protein gene protein 9.5 (PGP 9.5)

Anti PGP 9.5 are neuronal marker antibodies. Slides were prepared and divided into three groups: group I had antigen retrieval using 10% formic acid; group II did not have antigen retrieval; and group III was a negative control (no primary antibodies). The protocol of the procedure please see Appendix 2.

II: Anti-calcitonin gene-related peptide (CGPR):

Anti CGRP is a sensory fibres marker. Slides were prepared and divided into three groups: group I had antigen retrieval using 10% formic acid; group II did not have antigen retrieval; and group III was a negative control (no primary antibodies). Positive control sections of skin and of axillary artery were processed in parallel as a quality control measure. For the protocol of the procedure see Appendix 2.

Statistics:

The repeatability and the reliability of the taken measurement were assessed by randomly selecting shoulders from those studied. Three measurements were taken on a three separate occasions by the researcher, while two other individuals took the measurements on two other occasions.

Chapter 4: Results

Statistics:

Kruskal-Wallis One Way Analysis of Variance on Ranks showed that there was no difference for a single observer between the same measurements taken on separate occasions (P<0.504); there was also no difference in measurements taken by different observers (P<0.759). These results indicate that the measurement methodology that was used is reliable and repeatable.

Kruskal-Wallis One Way Analysis of Variance on Ranks
Interobserver results

Group	N	Missing	Median	25%	75%
Observer 1	47	0	4.040	3.160	5.310
Observer 2	47	0	3.690	2.950	5.680
Observer 3	47	0	3.660	3.090	4.950

H = 0.551 with 2 degrees of freedom. (P = 0.759)

Kruskal-Wallis One Way Analysis of Variance on Ranks
Intraobserver results

Group	N	Missing	Median	25%	75%
Observer 1	47	0	4.140	3.668	4.819
Observer 1	47	0	3.800	3.000	5.112
Observer 1	47	0	3.970	3.455	4.673

H = 1.369 with 2 degrees of freedom. (P = 0.504)

Part 1

Blood supply of the glenoid labrum

The blood supply to the glenoid labrum was observed during dissection of 140 shoulders from 30 males and 40 females, with an average age of 81.5 years (range 53-101 years). The labrum was exposed and divided into six regions: superior, anterosuperior, anteroinferior, inferior, posteroinferior and posterosuperior. The blood vessels identified are direct branches from the 2nd part of the axillary artery (ascending glenoid artery), subscapular, circumflex scapular, anterior circumflex humeral and posterior circumflex humeral arteries, as well as branches from muscular arteries from the surrounding muscles and the cortical blood supply from the underlying bone.

4.1. Ascending glenoid artery

The ascending glenoid artery was a branch arising from the first, second or third parts of the axillary artery in 1.80% (n=2), 92.50% (n=130) and 5.70% (n=4) respectively. It was found as one branch in 91.40% (n=128), two branches in 7.9% (n=11) and three branches in 0.70% (n=1) (Figure 4.1.1). The mean length and diameter in both genders were 34.6mm and 1.22mm respectively (Table 4.1.1). The mean length and diameter in males and females were 36.4mm, 1.25mm and 33.20mm, 1.20mm respectively (Table 4.1.1). Based on gender and side, the length and diameter of the ascending glenoid artery were variable, being longer and wider in males: only the length between males and females was statistically significant (P=0.057). The branches of the ascending glenoid artery supply subscapularis, the superior and anterosuperior aspects of the fibrous capsule, the glenohumeral ligaments, the superior and anterosuperior aspect of the glenoid labrum, glenoid neck, coracoid process, both heads of biceps brachii tendons and their origin, coracobrachialis and the rotator cuff muscle tendons.

Table 4.1.1: Comparison of the mean length and diameter of the ascending glenoid artery in males and females.

Descriptive statistics	Both genders		Males		Females	
	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)
Mean	34.6	1.2	36.4	1.3	33.2	1.2
Range	20.2 - 62.1	0.4 - 2.8	20.5 - 62.1	0.6 - 2.2	20.2 - 62.1	0.4- 2.8
Standard deviation	9.80	0.36	10.38	0.33	9.86	0.39

First ascending glenoid branch: was the most distal branch and passes superiorly and posteriorly to pierce subscapularis at the level of the anterior aspect of the glenoid rim and glenoid labrum. Within the substance of subscapularis, it divided into two main branches with each branch dividing further supplying the muscle and anterior aspect of the fibrous capsule and glenohumeral ligaments of the glenohumeral joint (Figure 4.1.1).

Second ascending glenoid branch: arose from the superior aspect of the second part of the axillary artery (Figure 4.1.1). It ascended slightly posteriorly to reach the superior aspect of the fibrous capsule of the shoulder joint and divided into three main branches (Figures 4.1.2, 4.1.3). The first branch passed laterally, parallel and anterior to the tendon of the long head of biceps until it reached the lesser tuberosity of the humerus (Figure 4.1.3). It gave 3 to 4 branches which pierced the superior aspect of the fibrous capsule going deep into the shoulder joint supplying the superior aspect of the rotator cuff, coracohumeral ligament and the superior aspect of the fibrous capsule (Figures 4.1.2, 4.1.3). The second branch ascended towards and supplied the medial aspect of the superior part of the fibrous capsule, the origin of the long head of biceps and superior aspect of the glenoid labrum (Figure 4.1.2). The third branch curved medially passing inferior to the root of the coracoid process to enter the suprascapular notch and the substance of subscapularis where it divided into many muscular branches (Figure 4.1.2).

Third ascending glenoid branch: was the most proximal from the superior aspect of the second part of the axillary artery. It ascended until it reached the superior aspect of the glenoid neck and divided into several branches (usually 4 or 5) supplying the coracoid process from its anterior aspect, the superior aspect of the glenoid rim and glenoid labrum, the coracohumeral ligament and superior aspect of the fibrous capsule (Figures 4.1.4, 4.1.5, 4.1.6).

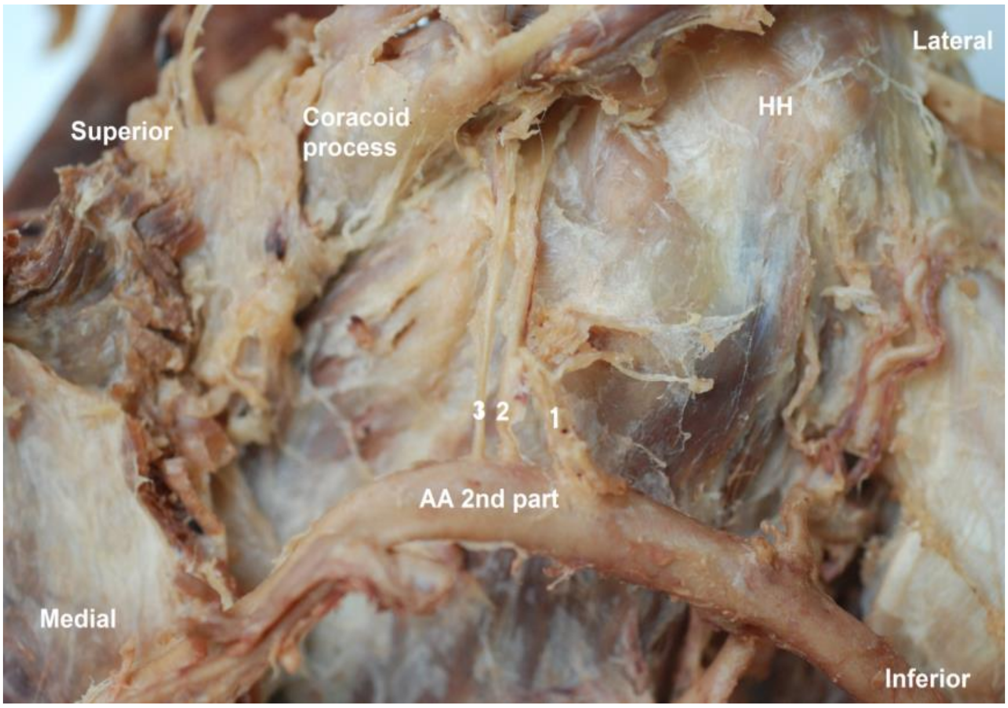


Figure 4.1.1: Anterior view of the left shoulder showing ascending glenoid branches arising from the 2nd part of axillary artery. AA: axillary artery; HH: humeral head.

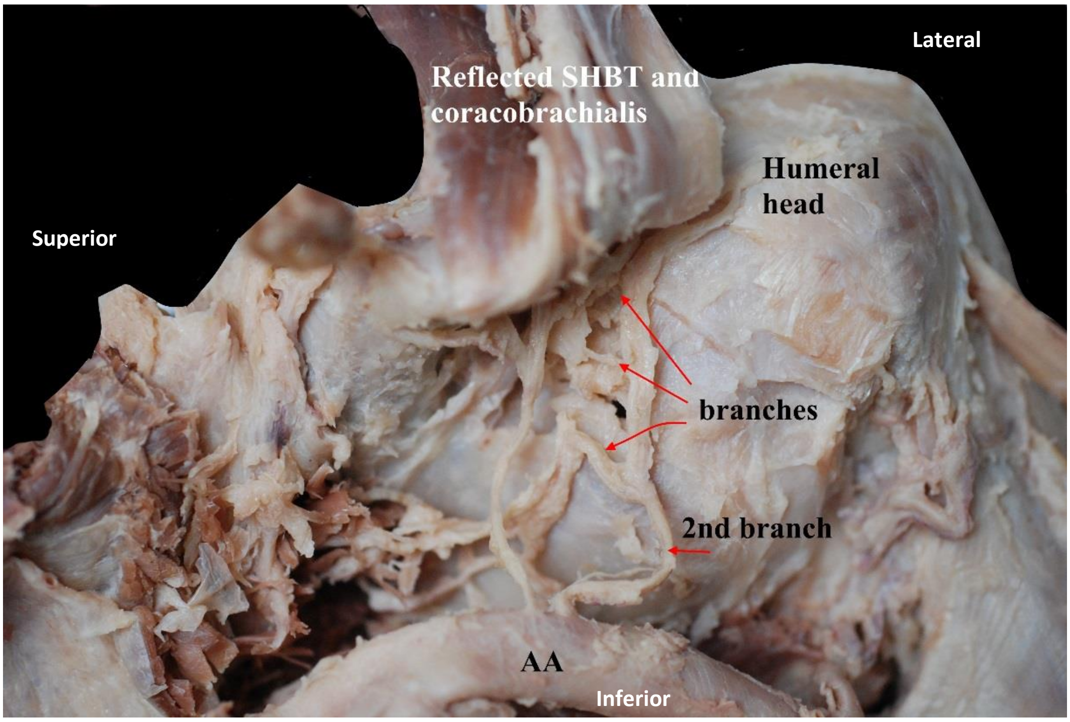


Figure 4.1.2: Anterior view of the left shoulder showing the branches of the second ascending glenoid branch arising from the 2nd part of the axillary artery. SHBT: short head of biceps tendon; AA: axillary artery.

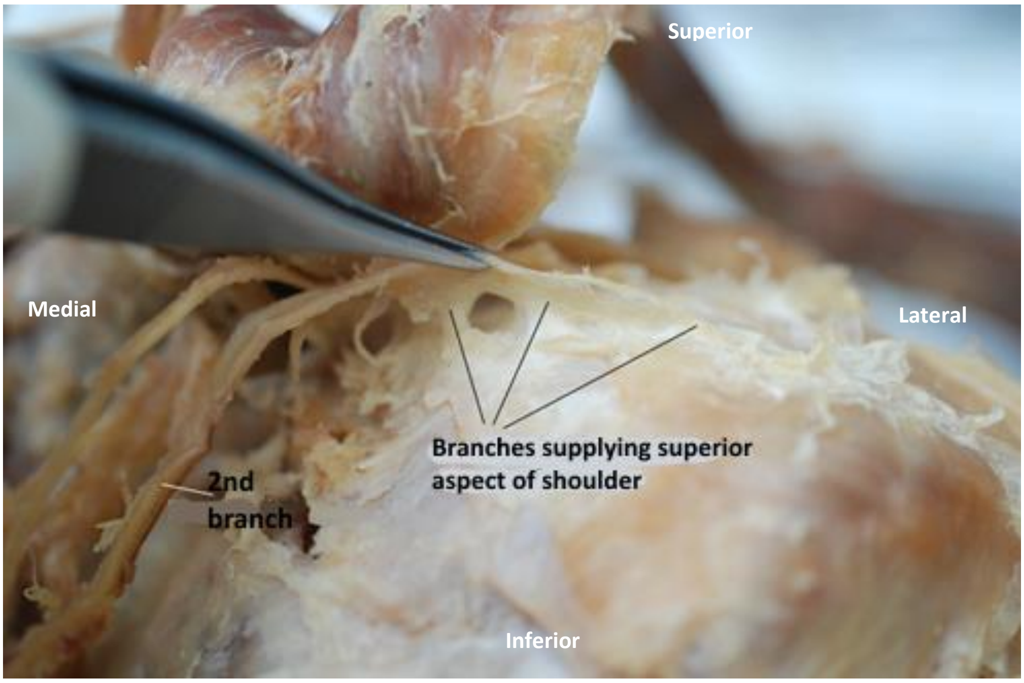


Figure 4.1.3: Anterolateral superior view of the left shoulder showing branches of the second ascending glenoid branch from the 2nd axillary artery.

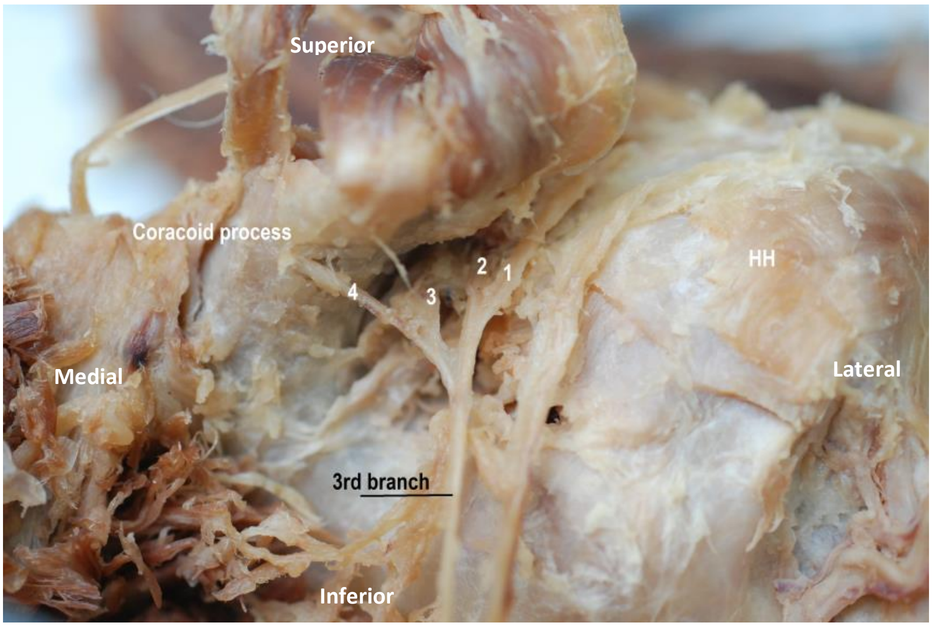


Figure 4.1.4: Anterior view of the left shoulder showing the 3rd ascending glenoid branch and its branches from the 2nd part of the axillary artery. HH: humeral head.

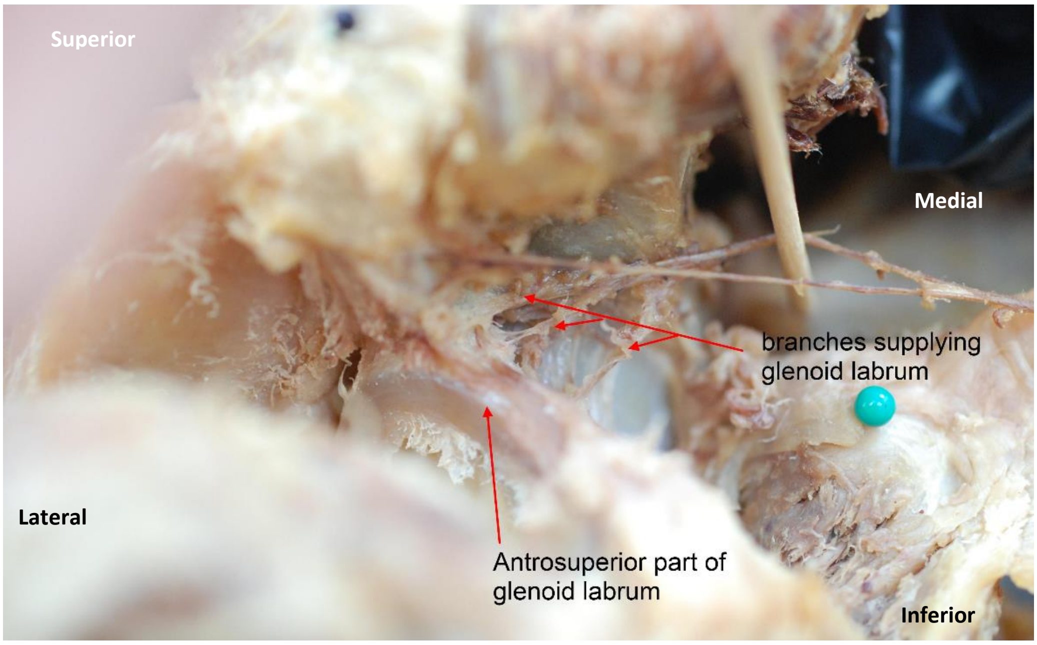


Figure 4.1.5: Anterosuperior lateral view of the right shoulder showing branches of the ascending glenoid branch supplying the superior and anterosuperior aspect of the glenoid labrum.

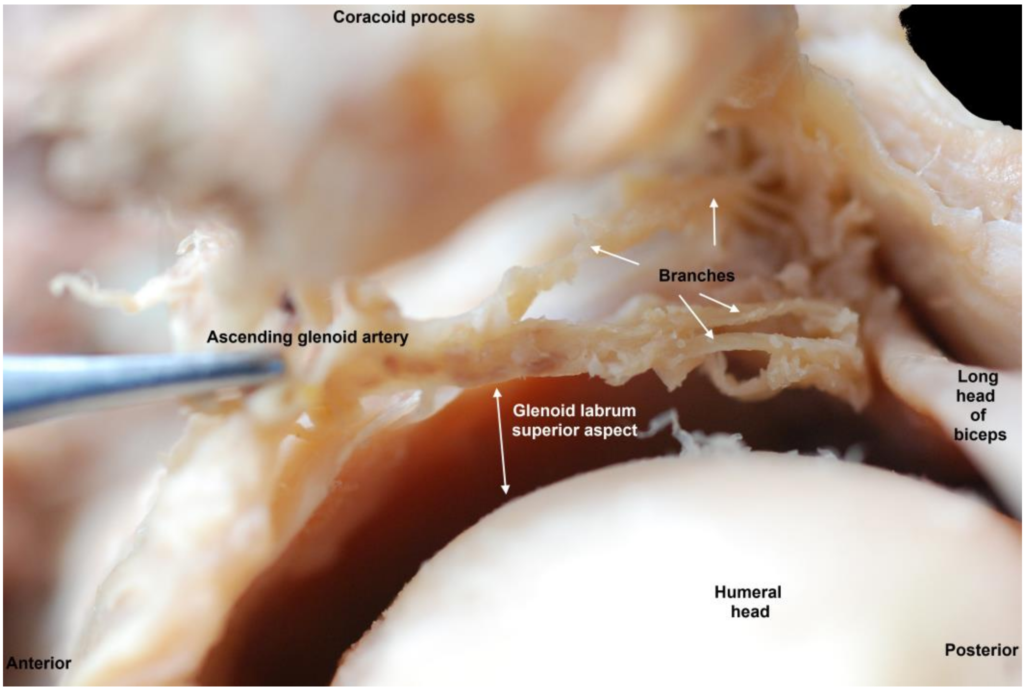


Figure 4.1.6: Lateral view of the right shoulder showing branches of the ascending glenoid artery supplying the superior and anterosuperior aspect of the glenoid labrum, the long head of biceps long (LHBT) and the surrounding structures. HH: humeral head.

4.2. Subscapular artery

The subscapular artery arose at the inferior border of subscapularis from the 3rd part of the axillary artery (88.60%, n=124), 1st part of the axillary artery (10.70%, n=15) or profunda brachii artery (0.70%, n=1), with an overall mean length (the subscapular and thoracodorsal arteries are measured as one artery) of 94.46mm and diameter 5.20mm (Table 4.2.1, Figure 4.2.1). The mean length in males and females was 96.97mm and 92.57mm respectively and the mean diameters 5.52mm and 4.97mm respectively (Table 4.2.1). Based on gender and side, the length and diameter of the subscapular artery was variable, being longer and wider in males: The differences in length and diameter between males and females were statistically significant (P=0.046 and P=0.008 respectively). It arose from the medial (68.60%, n=96), posteromedial (16.40%, n=23), inferomedial (0.70%, n=1), inferior (9.3%, n=13) or posterior aspect of the axillary artery (5%, n=7) and descended slightly posterior to run on the lateral border of the scapula as far as the inferior angle.

Table 4.2.1: Comparison of the mean length and diameter of the subscapular artery in males and females.

Descriptive statistics	**Both genders**		**Males**		**Females**	
	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)
Mean	94.5	5.2	97.0	5.5	92.6	5.0
Range	66.1 133.9	2.3 8.5	66.1 133.9	2.5 8.5	72.7 130.4	2.3 8.0
Standard deviation	12.95	1.21	13.04	1.25	12.64	1.13

Branches:

1. Muscular to latissimus dorsi, subscapularis, teres major and serratus anterior.

2. Circumflex scapular artery

3. Cutaneous branches to the skin of the lateral wall of the thorax just inferior to the axilla.

4. It occasionally gives an inferior glenoid artery (page 224).

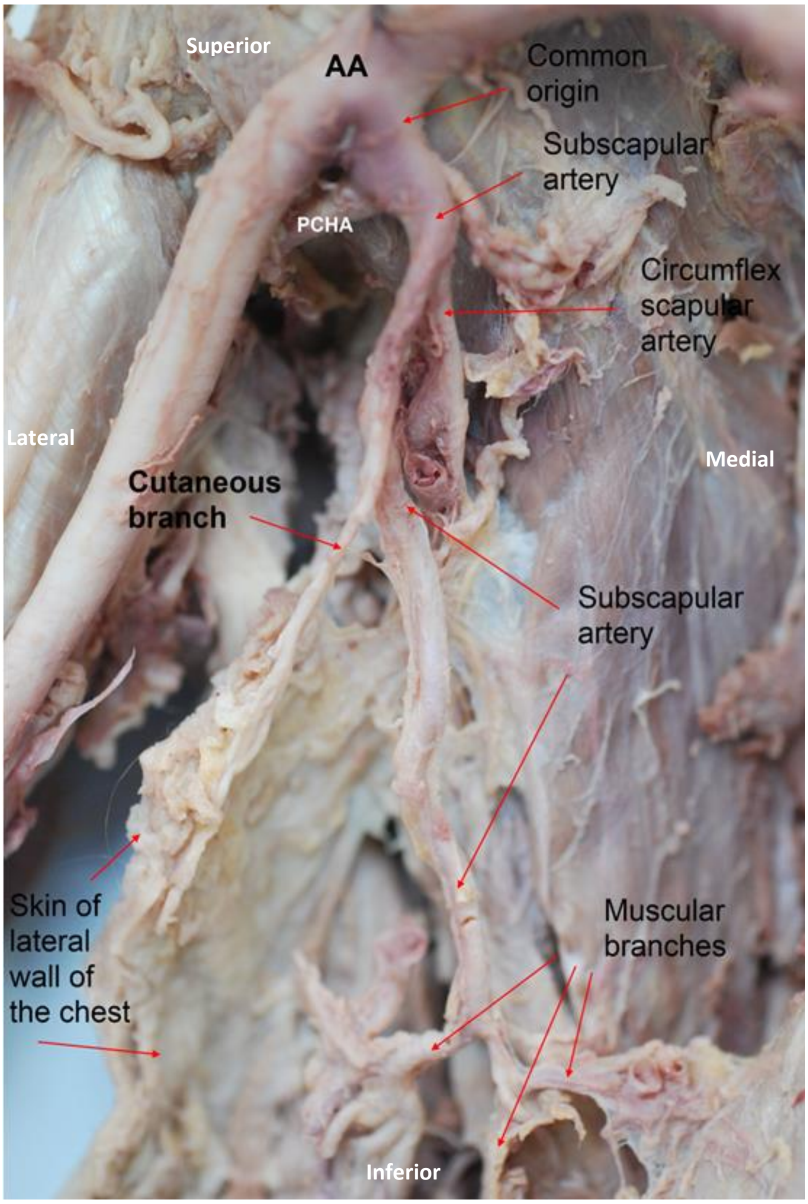


Figure 4.2.1 Anterior view of the right shoulder showing the subscapular artery arising from the 3rd part of the axillary artery (AA) as a common origin with the posterior circumflex humeral artery (PCHA) and its branches.

4.3. Circumflex scapular artery

The circumflex scapular artery arose from the subscapular artery 10 – 30 mm from its origin (97.9%, n=137) (Figures 4.2.1, 4.3.1), the profunda brachii (0.70%, n=1) or the third part axillary artery (1.40%, n=2). The site of origin was posterior (60.7%, n=85), posterolateral (27.9%, n=39), lateral (7.9%, n=11), posteromedial (2.1%, n=3) or medial (1.4%, n=2). The mean length and diameter of all specimens and for males and females separately are presented in Table 4.3.1. Based on gender and side, the length and diameter of the subscapular artery were variable, being longer and wider in males: The length and diameter were significantly different between males and females (P=0.001 and P=0.001 respectively), but were not significant between sides.

The artery curved posteriorly to pass through the triangular space then downwards for 30 – 40 mm before curving posteriorly to run between teres minor anterior and teres major posterior. It ramified inside infraspinatus and shared in the anastomoses around the scapula (Figures 4.3.1, 4F, 4G).

Table 4.3.1: Comparison of the mean length and diameter of the circumflex scapular artery in males and females.

Descriptive statistics	**Both genders**		**Males**		**Females**	
	Length (mm)	**Diameter** (mm)	**Length** (mm)	**Diameter** (mm)	**Length** (mm)	**Diameter** (mm)
Mean	95.0	3.8	99.2	4.0	91.8	3.6
Range	67.8 124.0	2.1 6.6	74.7 124.0	2.2 6.6	67.8 108.9	2.1 5.3
Standard deviation	10.62	0.72	10.56	0.78	9.54	0.62

Branches:

1st branch: (see page 224) is known as the inferior glenoid artery and occasionally arose from the circumflex scapular artery. It ran superiorly passing through subscapularis to reach the distal attachment of the inferior aspect of the fibrous capsule of the shoulder joint. After careful microdissection to track the termination of the artery and careful removal of the inferior aspect of the fibrous capsule this branch was observed to pass through the inferior aspect of the capsule dividing into two branches before piercing the inferior region of the glenoid labrum at 6 o'clock and supplying it. This branch supplied subscapularis, the inferior aspect of the fibrous capsule and terminated in the glenoid labrum at 6 o'clock (Figures 4.3.1 to 4.3.6a).

2nd branch: a muscular branch which arose 30 mm from its origin where it then passed inferomedially undercover of subscapularis supplying it at the middle of its lateral border (Figure 4.3.1).

3rd branch: arose 30 mm from its origin and ran deep to subscapularis as far as 30 mm from the inferior aspect of the glenoid rim. At the anterior ridge of the lateral border it divided into three branches (superior, middle and inferior). The superior branch ran superior as far as 30 mm from the anterior glenoid rim then curved medially and ramified as muscular, nutrient and periosteal branches in the upper 1/3rd of the subscapular fossa. As the artery curved close to the shoulder joint it gave periosteal branches to supply the anterior, anteroinferior and anterosuperior aspects of the glenoid rim and glenoid labrum. The middle (infrascapular) branch ran medially to the middle of the subscapular fossa where it supplied subscapularis and the subscapular fossa. The inferior branch ran inferomedially to supply the lower 1/3rd of the subscapular fossa and subscapularis (Figures 4.3.6a and b, 4.3.7).

4th branch: a nutrient branch which arose 30 mm from its origin at the anterior aspect of the lower border of the origin of the long head of triceps. It descended inferiorly for 15 mm and penetrated the lateral border of the scapula (Figure 4.3.6a).

5th branch: a muscular branch which arose 30 mm from its origin running for a short distance on the lower border of the long head of triceps then it ramifying in it (Figure 4.3.6a).

6th branch: arose from the circumflex scapular artery about 30 mm from the inferior border of the long head of triceps where it descended 30 – 35 mm on the lateral border of the scapula terminating close to the inferior angle by supplying subscapularis and the lateral border of the scapula (Figure 4.3.6a).

7th branch: present in 74.42% (n=104) of specimens with a mean diameter of 2.99 mm. It is named an ascending branch which arose from the circumflex scapular artery 30 mm from its origin, at the lower border of the origin of the long head of triceps (Figures 4.3.7, 4.3.9). It ascended superomedially, passing posterior to the origin of the long head of triceps grooving the bone for a short distance accompanied by two veins (sometimes one) (Figure 4.3.8), towards the inferior aspect of the spinoglenoid notch then curved medially to run in the infraspinous fossa just inferior to the root of the spine of the scapula terminating by giving several superior and inferior branches supplying infraspinatus, teres minor and the infraspinous fossa. Its branches were: (1) at the inferior aspect of the spinoglenoid foramen which ran on the posteroinferior aspect of the fibrous capsule supplying the glenoid rim, fibrous capsule and glenoid labrum; (2) at the inferior aspect of the spinoglenoid notch it gave an ascending branch which ran through the spinoglenoid notch, lateral to the suprascapular vessels, to the supraspinous fossa giving nutrient branches to the inferior aspect of the acromion process, acromioclavicular joint, muscular branches to supraspinatus, nutrient branches to the superior aspect of the glenoid neck and a small branch, via the suprascapular notch, to the subscapular fossa; (3) nutrient branches to the posteroinferior aspect of the glenoid neck and glenoid rim; (4) muscular branches to infraspinatus and teres minor; and (5) periosteal and nutrient branches supplying the infraspinous fossa and inferior aspect of the root of the spine of the scapula (Figures 4.3.9 to 4.3.11).

8th branches: muscular to teres minor, major, infraspinatus and subscapularis.

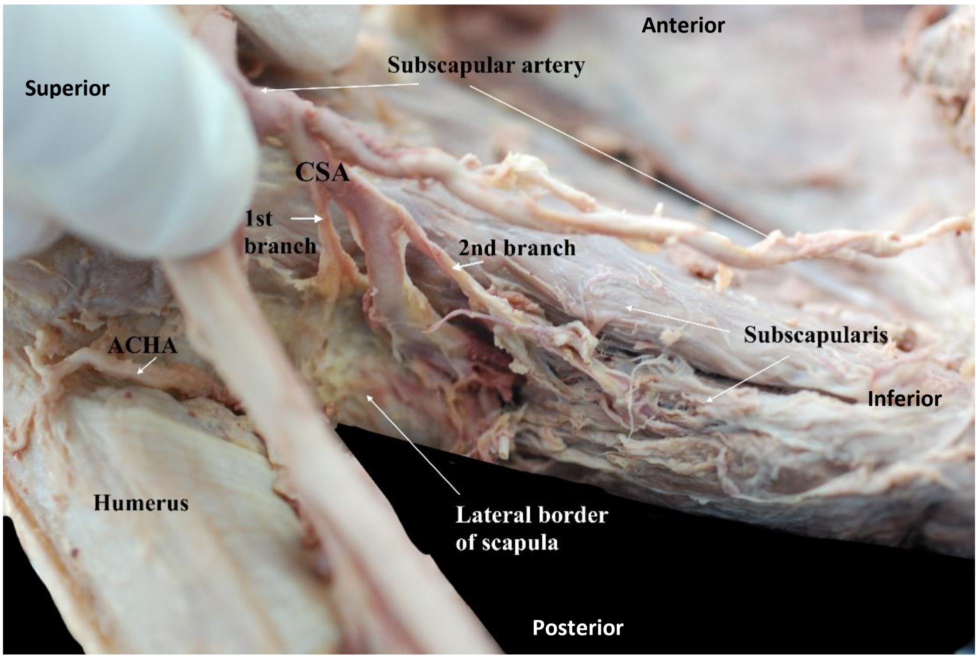


Figure 4.3.1: Anteromedial view of the right shoulder showing the axillary artery giving the subscapular artery and its branches. CSA: circumflex scapular artery, 1st is the inferior glenoid artery, 2nd branch is the muscular branch.

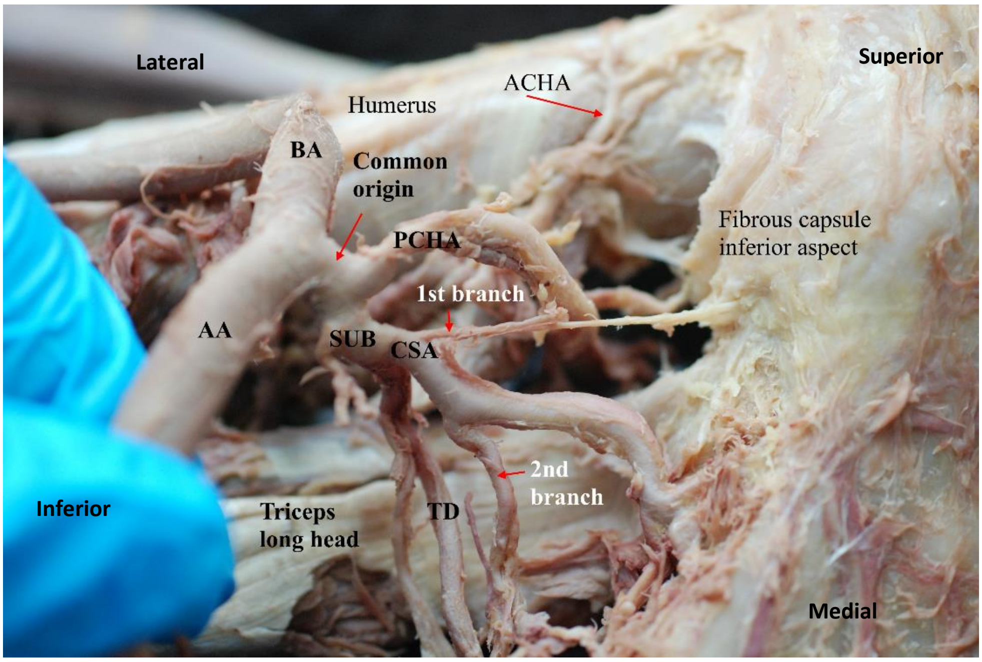


Figure 4.3.2: Anterolateral view of the right shoulder showing the reflected axillary artery (AA) giving a common origin of posterior circumflex humeral artery (PCHA) and subscapular artery. The subscapular artery gives circumflex scapular artery (CSA) which then gives 1st branch (inferior glenoid artery); TD: thoracodorsal artery.

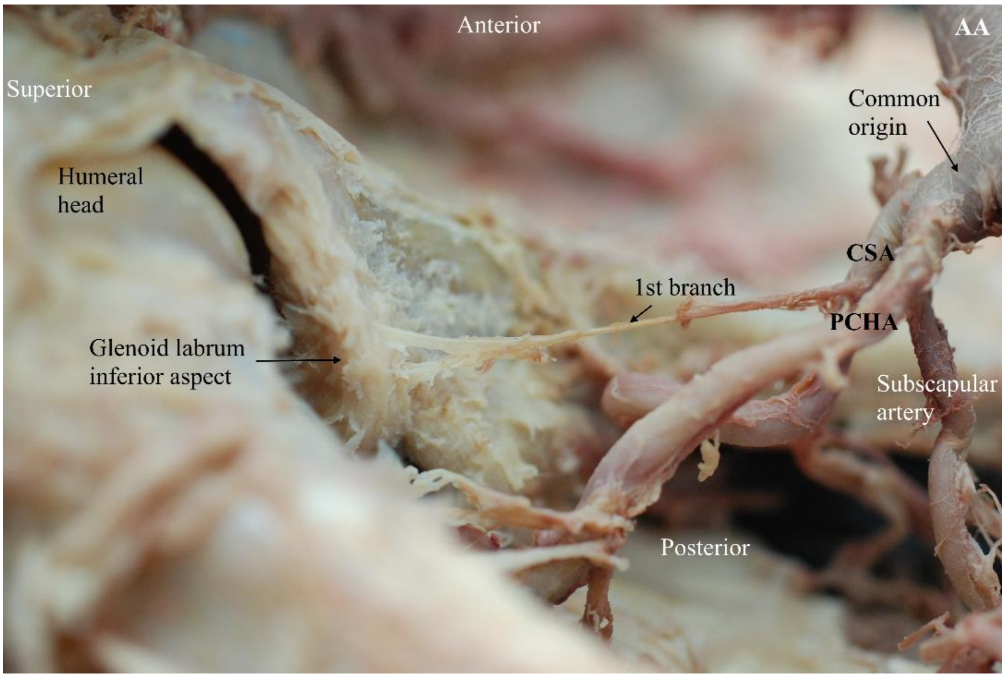


Figure 4.3.3: Lateral view of the right shoulder showing the 1st branch (inferior glenoid branch) arises from circumflex scapular artery (CSA) entering the inferior fibrous capsule and the glenoid labrum at 6 o'clock. AA: axillary artery, PCHA: posterior circumflex humeral artery.

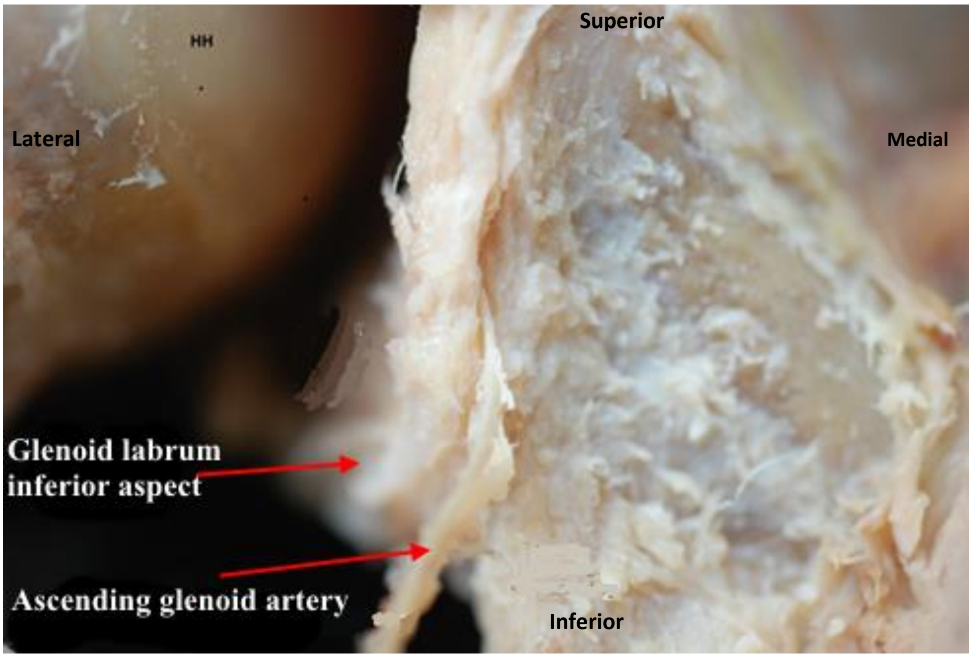


Figure 4.3.4: Inferior view of the right shoulder shows the 1st branch (inferior glenoid branch) arising and entering the glenoid labrum at 6 o'clock. HH: humeral head.

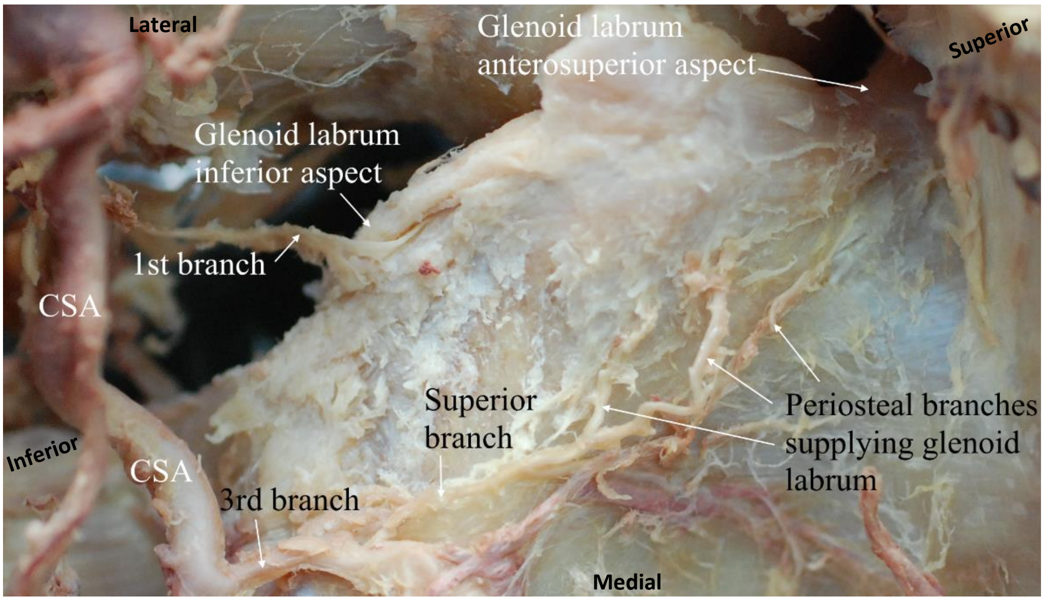


Figure 4.3.5: Anteroinferior view of the right shoulder showing some branches of circumflex scapular artery (CSA): the 1st branch (inferior glenoid artery), part of the 3rd branch.

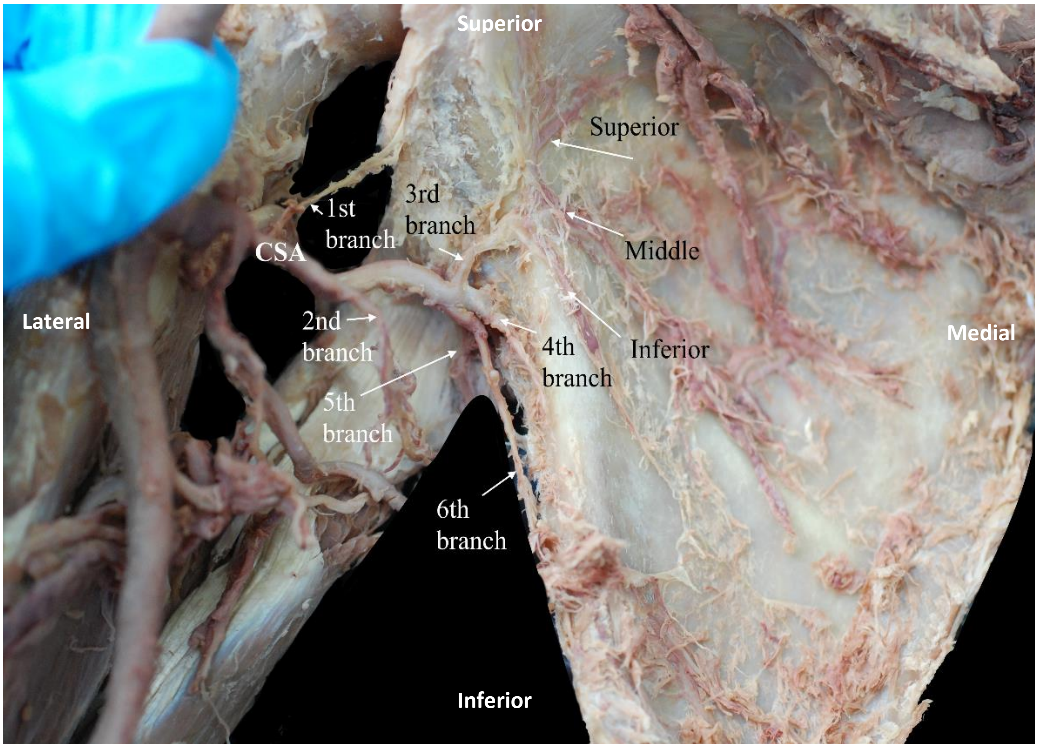


Figure 4.3.6a: Anterior view of the right scapula showing axillary artery (reflected), circumflex scapular artery (CSA) and its branches which are: 1st branch (inferior glenoid artery), 2nd branch, 3rd branch, 4th branch, 5th branch and 6th branch.

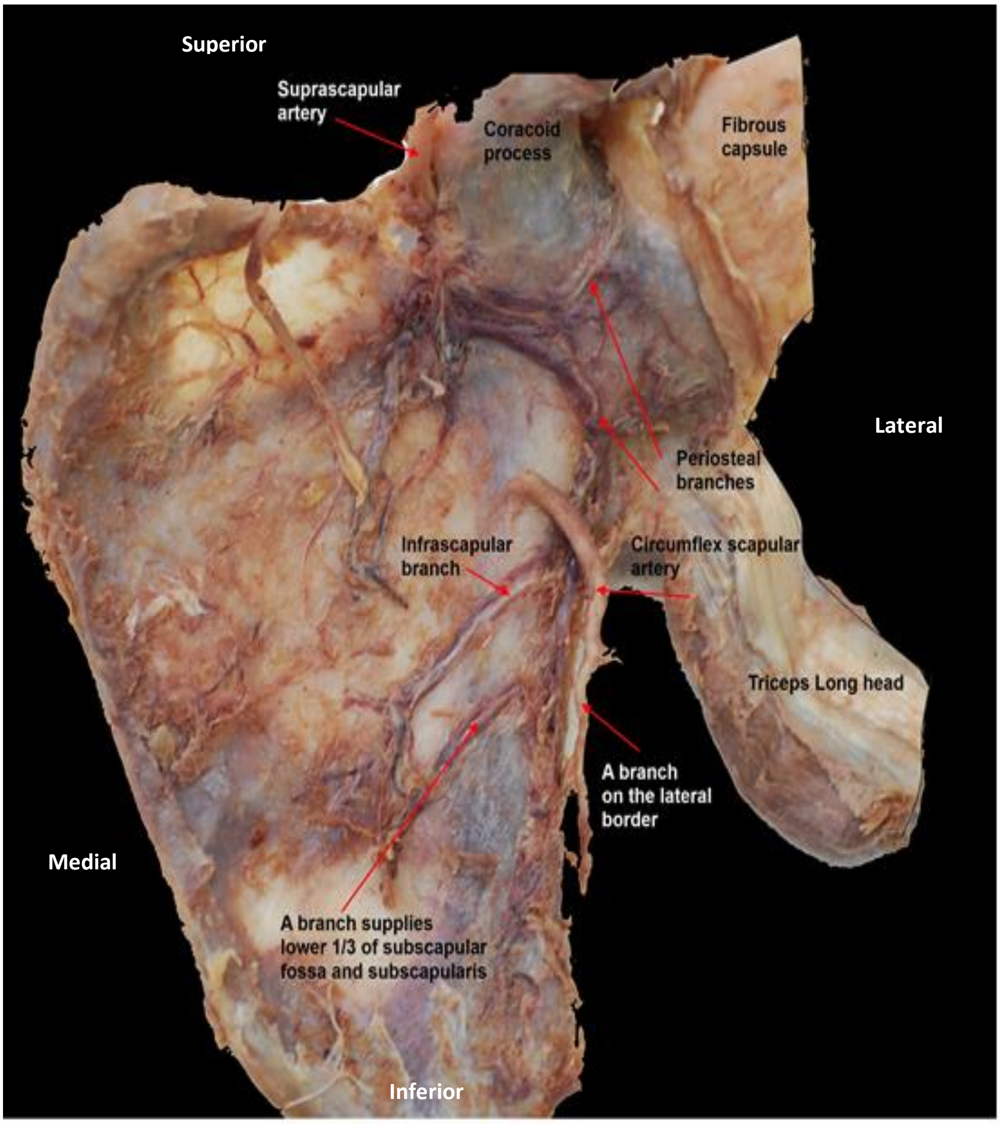


Figure 4.3.6b: Anterior view of left scapula showing the periosteal branches of the circumflex scapular artery which supply the anterosuperior aspect of the glenoid labrum.

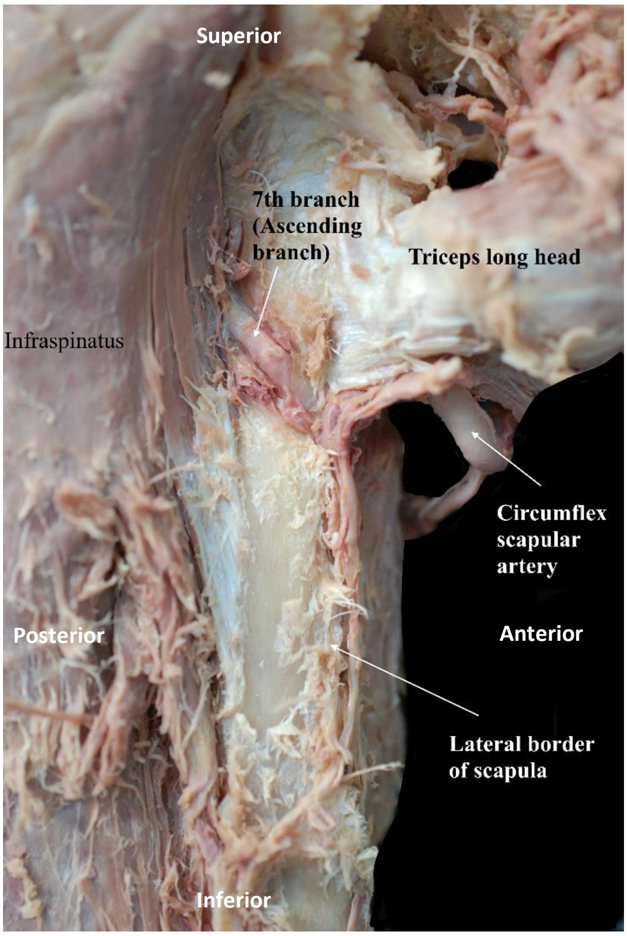


Figure 4.3.7: Posterolateral view of the right scapular showing circumflex scapular artery, the 7th branch (ascending branch of circumflex scapular), long head of triceps, partially reflected infraspinatus.

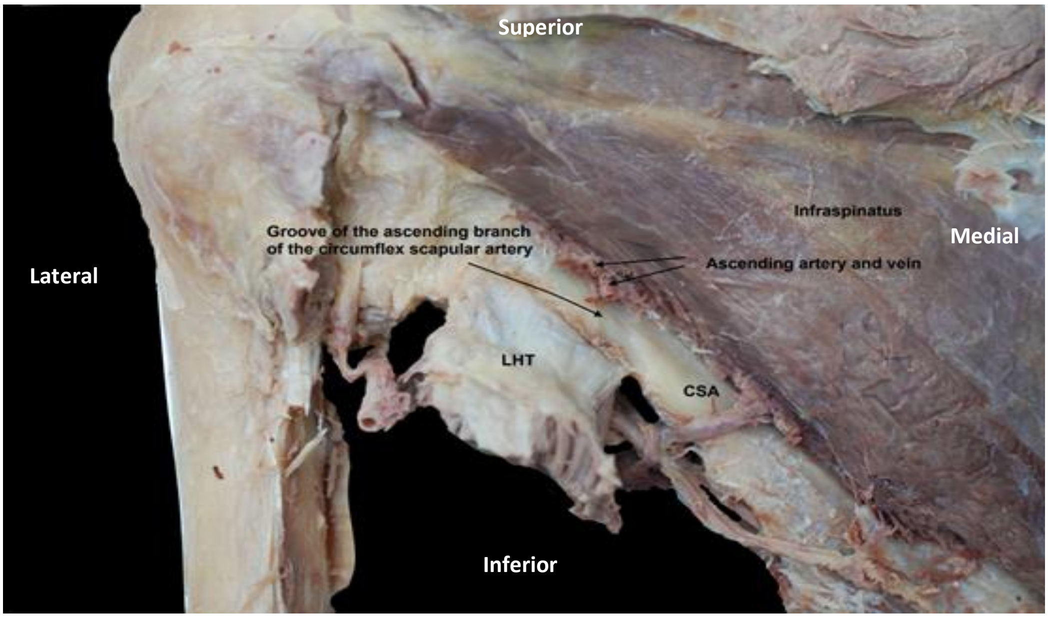


Figure 4.3.8: Posterior view of the left shoulder showing the groove for the ascending branch of the circumflex scapular artery and accompanying veins. CSA: circumflex scapular artery. LHT: long head of triceps.

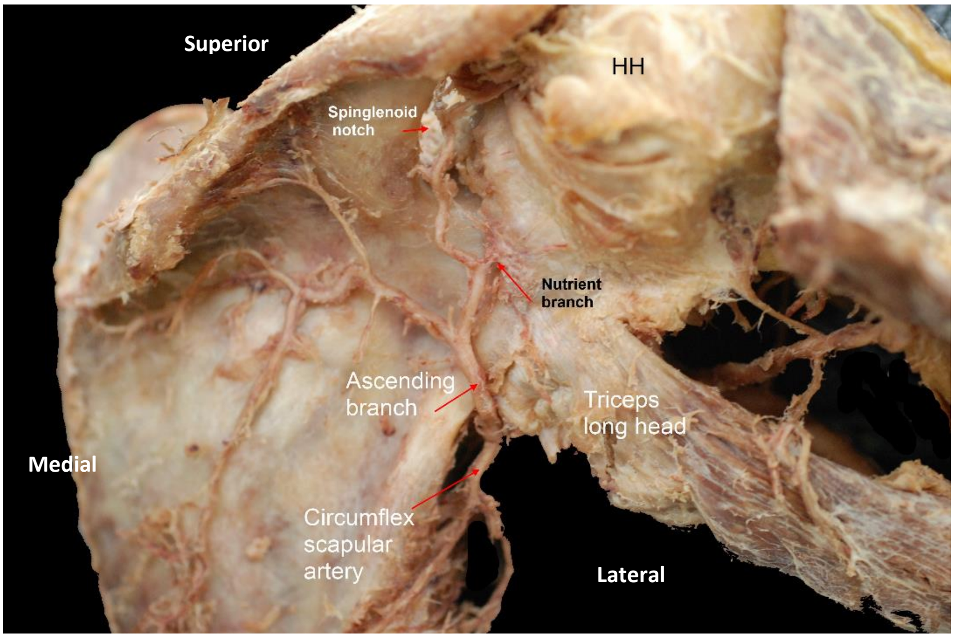


Figure 4.3.9: Posterior view of the right scapula showing the ascending branch of the circumflex scapular artery. HH: humeral head.

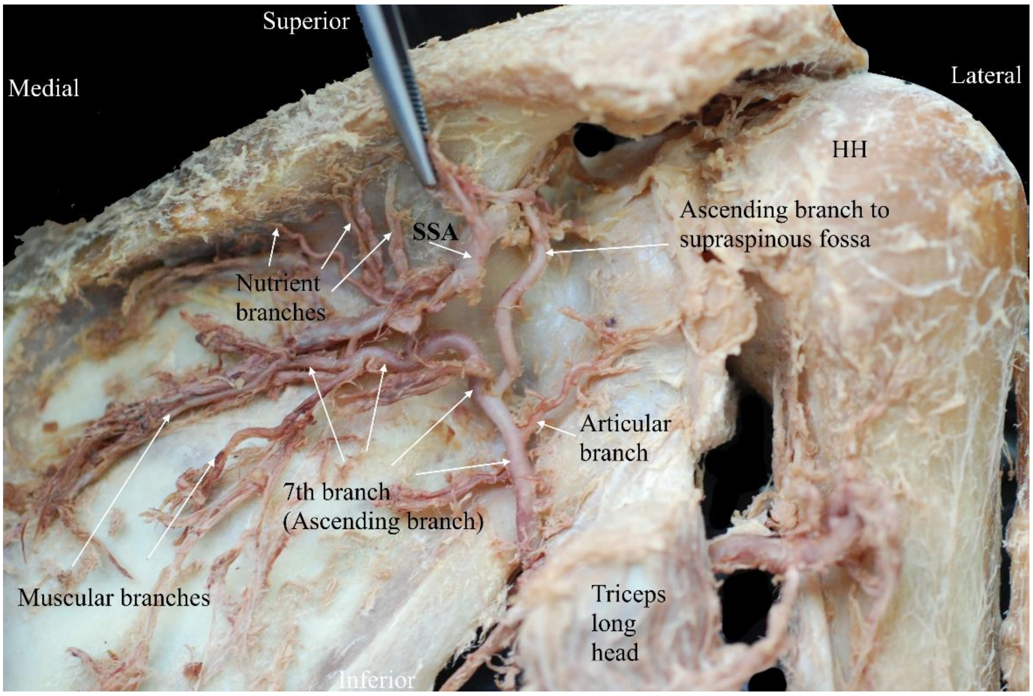


Figure 4.3.10: Posterior view of the right shoulder showing branches of the ascending branch of the circumflex scapular artery. SSA: suprascapular artery; HH: humeral head.

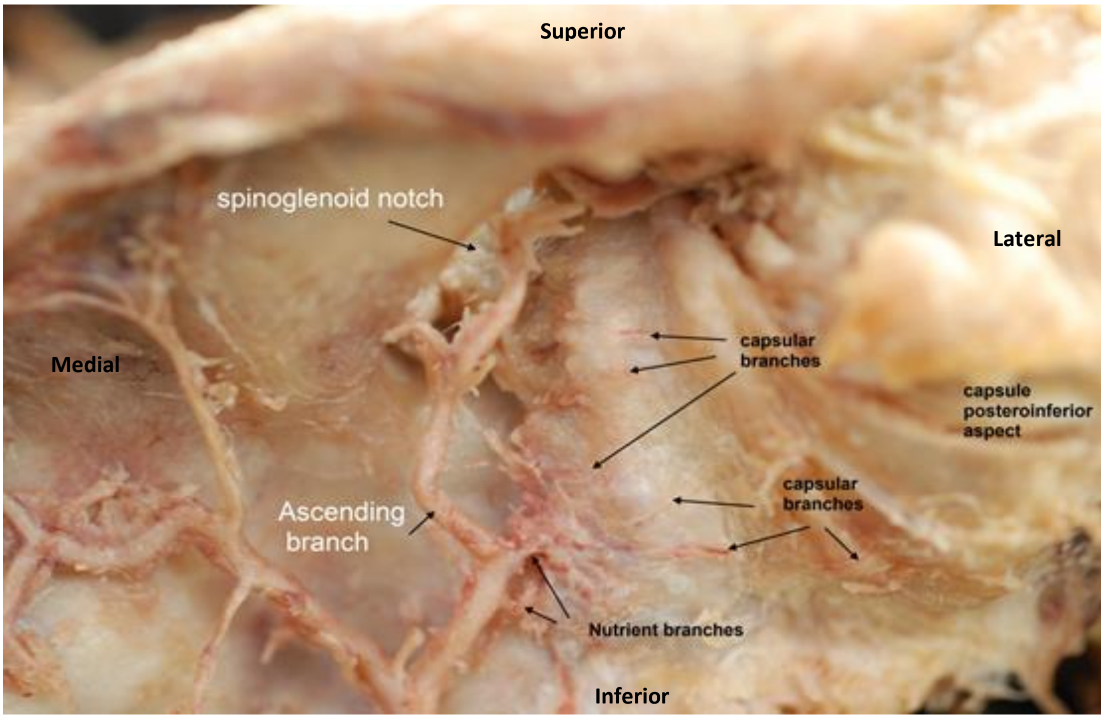


Figure 4.3.11 Posterior view of the right shoulder showing the capsular branches of the ascending branch of the circumflex scapular artery.

4.4. Inferior glenoid artery

As this branch supplied the inferior aspect of the glenoid labrum it is named the inferior glenoid artery: it was present in 82.85% (n=117) of specimens. It arose from the posterior circumflex humeral artery (29.9%, n=35) with a mean of length and diameter of 23.66mm and 1.22mm, the circumflex scapular artery (54.7%, n=64) with a mean of length and diameter of 28.81mm and 1.16mm, and the subscapular artery (15.4%, n=18) with a mean of length and diameter of 27.35mm and 1.29mm (Table 4.4.1). Based on gender and side, there was no significant difference between males and females. It was found as a single (81.2%, n=95), double (17.95%, n=21) or triple (0.85%, n=1) branch arising from each of the above arteries. It passed superiorly through subscapularis to reach the distal attachment of the inferior aspect of the fibrous capsule of the shoulder joint. After careful microdissection to identify its termination and careful removal of the inferior aspect of the fibrous capsule it was observed to pass through the inferior aspect of the fibrous capsule and then divided into two branches before piercing the inferior region of the glenoid labrum between 5 and 7 o'clock supplying it. The branches supplied subscapularis, the inferior aspect of the fibrous capsule and terminated in the glenoid labrum at 6 o'clock (Figures 4.3.1 to 4.3.6).

Table 4.4.1: Comparison of the mean length and diameter of the inferior glenoid artery in males and females.

Descriptive statistics	Both genders		Males		Females	
	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)
Mean	27.6	1.2	28.0	1.2	27.2	1.2
Range	13.7 44.0	0.6 2.1	14.2 42.8	0.6 2.1	13.7 44.0	0.6 1.9
Standard deviation	6.13	0.30	6.26	0.32	5.85	0.28

4.5. Anterior circumflex humeral artery

The anterior circumflex humeral artery arose from the 3rd part of the axillary artery (87.1%, n=122), the posterior circumflex humeral artery (10.7%, n=15) and profunda brachii (2.1%, n=3). The site of origin was either lateral (70.7%, n=99), posterolateral (17.9%, n=25), superior (5.7%, n=8), anterolateral (2.9%, n=4), posterosuperior (0.7%, n=1) posterior (0.7%, n=1) anterosuperior (0.7%, n=1) or anterior (0.7%, n=1). It ran laterally undercover of the short head of biceps and coracobrachialis to wind around the surgical neck of the humerus where it ramified in deltoid and anastomosed with the posterior circumflex humeral artery (Figures 4.5.1-4.5.3). The mean length and diameter in both genders were 61.76 mm and 2.14 mm respectively. The mean length and diameter in males and females were 60.18 mm, 2.17 mm vs 60.18 mm, 2.12 mm (Table 4.5.1). Based on gender and side there was no significant difference in length or diameter.

Table 4.5.1: Comparison of the mean length and diameter of the anterior circumflex humeral artery in males and females.

Descriptive statistics	All		Males		Females	
	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)
Mean	60.85	2.14	61.76	2.17	60.18	2.12
Range	32.33 80.19	1.07 3.97	32.33 78.49	1.09 3.6	45.35 80.19	1.07 3.97
Standard deviation	8.33	0.56	8.71	0.55	8.03	0.57

Branches:

1. 1st ascending branch: observed in 98.57% (n=138) of specimens running superiorly just medial to the anterior aspect of the anatomical neck of the humerus. It then divided into two branches piercing subscapularis and the fibrous joint capsule and terminated by supplying the anteroinferior and anterior aspect of the anatomical neck of the humerus, the fibrous capsule, subscapularis and the anterior aspect of the surgical neck of the humerus (Figures 3.5.1-3.5.3).

2. 2nd ascending branch: was present in 94.42% (n=135) of specimens arising from the superior aspect of the anterior circumflex humeral artery. It ascended on the anterior aspect of the anatomical neck medial to the lesser tuberosity. It terminated by dividing into three branches. The first and the second branches ascended and pierced subscapularis and the anterior part of the fibrous capsule supplying subscapularis, the anterior part of the fibrous capsule and the anterior and anterosuperior aspect of the anatomical neck. The third branch ran towards the lesser tuberosity to supply it and the adjacent bone. An additional ascending branch was found in 3.57% (n=5) of specimens arising from the superior aspect of the anterior circumflex humeral artery between the second and third ascending branches (Figures 4.5.1 - 4.5.3).

3. 3rd ascending branch: was present in 98.57% (n=138) of specimens arising from the anterior circumflex humeral artery (97.10%, n=134), brachial artery (2.2%, n=3) or profunda brachii (0.7%, n=1). It ran superiorly into the bicipital groove on the posterior aspect of the tendon of long head of biceps to enter the fibrous capsule of the shoulder joint. It gave nutrient branches to the bicipital groove and anterior aspect of the greater tuberosity (Figures 4.5.1-4.5.3).

These ascending branches supplied the fibrous capsule, the surrounding structures and contributed indirectly in supplying the glenoid labrum through its attachment to the joint capsule and adjacent bone.

4. Muscular branches to deltoid, biceps, coracobrachialis, teres major and latissimus dorsi.

5. Nutrient branches to the anterior, anterolateral and lateral aspects of the surgical neck of the humerus.

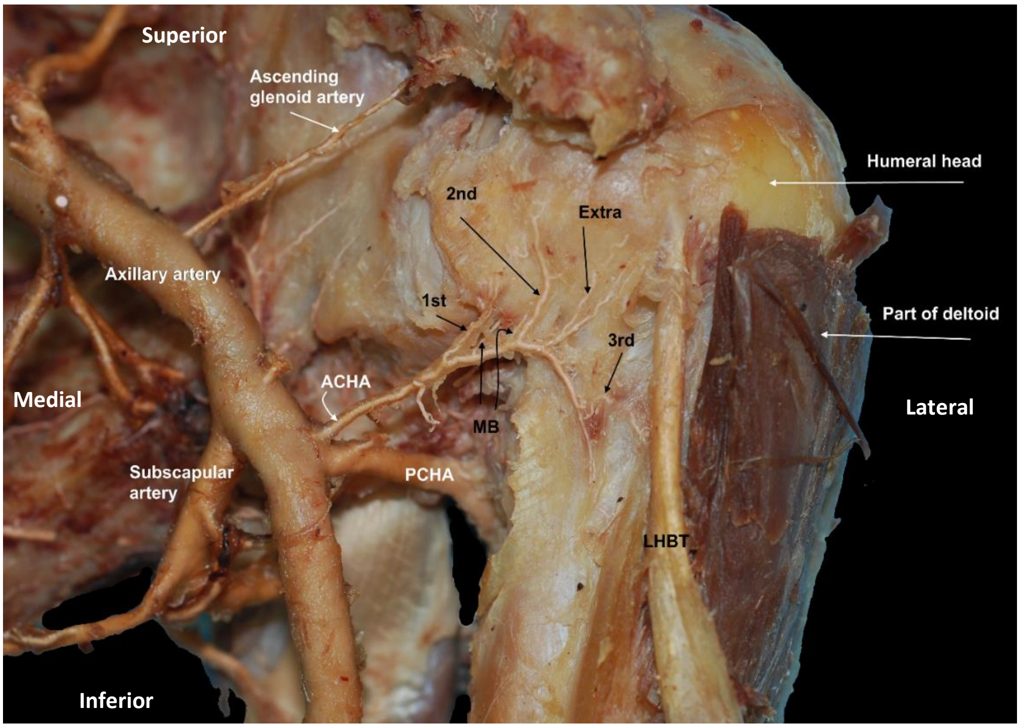


Figure 4.5.1: Anterolateral view of the left shoulder injected with coloured silcone showing branches of the anterior circumflex humeral artery (ACHA).

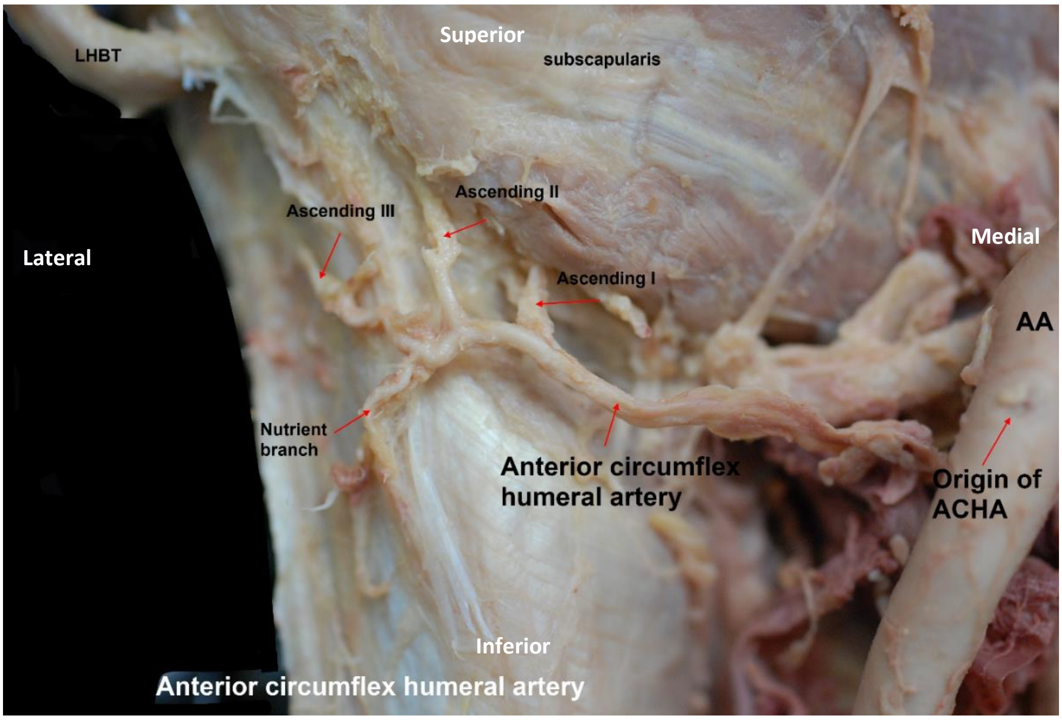


Figure 4.5.2: Anterior view showing the anterior circumflex humeral artery and its branches. AA: axillary artery, ACHA: anterior circumflex humeral artery, LHBT: long head of biceps tendon.

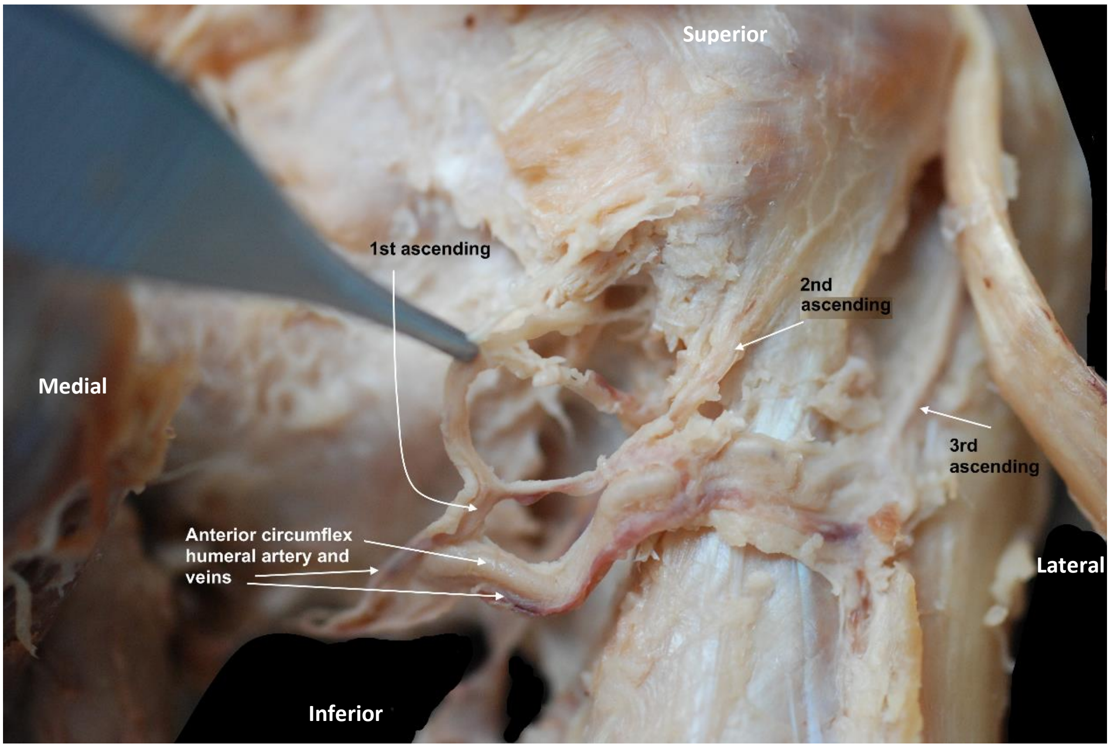


Figure 4.5.3: Anterior view of the left shoulder showing branches of the anterior circumflex humeral artery.

4.6. Posterior circumflex humeral artery

The posterior circumflex humeral artery had a variable origin (Figures 4.3.2, 4.6.1), with an average diameter of 3.98 mm and length 67.11 mm (Table 4.6.1). It arose at the level of the lower border of subscapularis from the 3rd part of the axillary artery (75.7%, n=106), profunda brachii (2.1%, n=3), circumflex scapular artery (1.4%, n=2), brachial artery (12.1%, n=17), or subscapular artery (8.6%, n=12). A detailed comparison of the posterior circumflex humeral artery is presented in Table 3.6.1. Based on gender and side, the length and diameter of the posterior circumflex humeral artery were variable, being longer and wider in males: there was no significant difference between males and females. The posterior circumflex humeral artery arose from the posterior (44.3%, n=62), lateral (19.3%, n=27), superior (2.9%, n=4), posterolateral (31.4%, n=44), inferolateral (1.4%, n=2) and posteromedial (0.7%, n=1) aspect of the artery and passed posterolateral to the anatomical neck of the humerus. It gave one branch (sometimes two), which then divided into several branches piercing the inferior aspect of the fibrous capsule of the shoulder joint before passing through the quadrangular space accompanied by the axillary nerve and posterior circumflex humeral vein to wind around the surgical neck of the humerus from its posterior aspect. Just after passing through the quadrangular space it gave a muscular branch to the long head of triceps. It then continued its course giving another branch which entered the fibrous capsule of the shoulder joint from its posteroinferior aspect. Once the artery reached deltoid it divided into three (posterior, middle and anterior) or four main branches, which then divided into 3 – 4 branches ramifying in deltoid. The posterior branch ran posteriorly within deltoid until it reached the posterior part of the surgical neck and divided into small branches supplying the surgical and anatomical necks of the humerus and deltoid (Figure 4.6.3).

Branches:

Before passing through the anatomical triangle it gave muscular branches to teres major, latissimus dorsi and subscapularis.

In the anatomical triangle:

Muscular branches were given to the long head of triceps. Nutrient branches were given to the medial side of the upper end of the humeral shaft 15 – 25 mm inferior to the surgical neck: they also supplied the anteroinferior and inferior aspect of the anatomical neck. Capsular branches passed through the fibrous capsule from its anteroinferior and inferior aspects running through the fibrous capsule for variable distances before entering the joint: they also supplied subscapularis, the glenohumeral ligaments and fibrous capsule. Passing medially through the fibrous capsule these branches supplied the inferior and posteroinferior aspects of the glenoid labrum (Figures 4.6.2-4.6.4).

After the anatomical neck:

Periosteal branches to the posterior aspect of the upper 1/3 of the shaft of the humerus. Muscular branches to deltoid, long head of triceps, teres minor and teres major. Capsular branches passed through the posterior and posteroinferior aspects of the fibrous capsule of the shoulder joint supplying it, teres minor and the inferoposterior and posterior aspects of the anatomical neck (Figure 4.6.3, 4.6.4).

Nutrient branches to the greater tuberosity and adjacent bone and to the posterior aspect of the surgical neck.

The posterior circumflex humeral artery sometimes gave a direct branch which ran to the inferior aspect of the fibrous capsule and ended by supplying subscapularis, the fibrous capsule and glenohumeral ligament and the inferior glenoid labrum (Figure

4.6.5). It also gave the profunda brachii (2.85%, n=4) and anterior circumflex humeral artery (12.14%, n=17).

Table 4.6.1: Comparison of the mean length and diameter of the posterior circumflex humeral artery in males and females.

Descriptive statistics	Both genders		Males		Females	
	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)
Mean	67.1	4.0	67.9	4.1	66.5	3.9
Range	47.5 92.3	1.2 7.4	47.5 92.3	1.2 6.5	48.0 89.1	2.2 7.4
Standard deviation	9.05	1.0	8.61	1.1	9.36	0.91

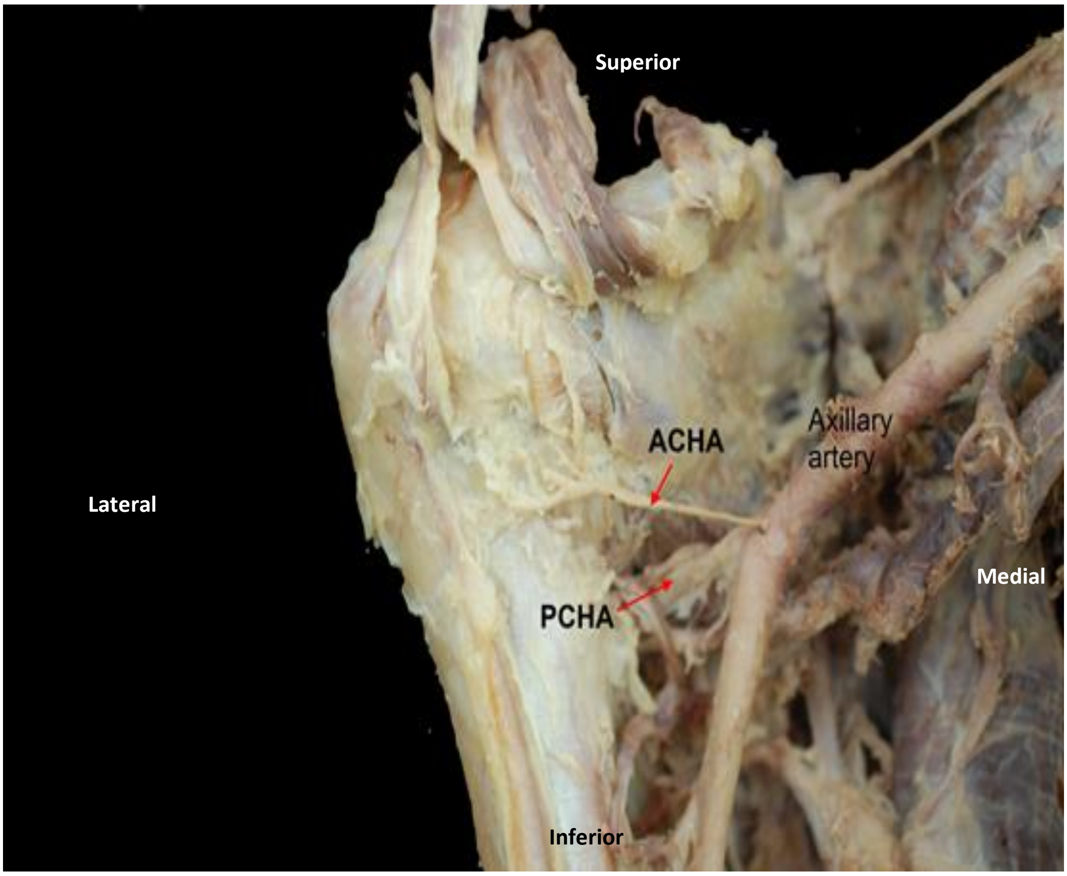


Figure 4.6.1: Anterior view of the right shoulder showing the origin of the posterior circumflex humeral artery (PCHA) from the axillary artery. ACHA: anterior circumflex humeral artery.

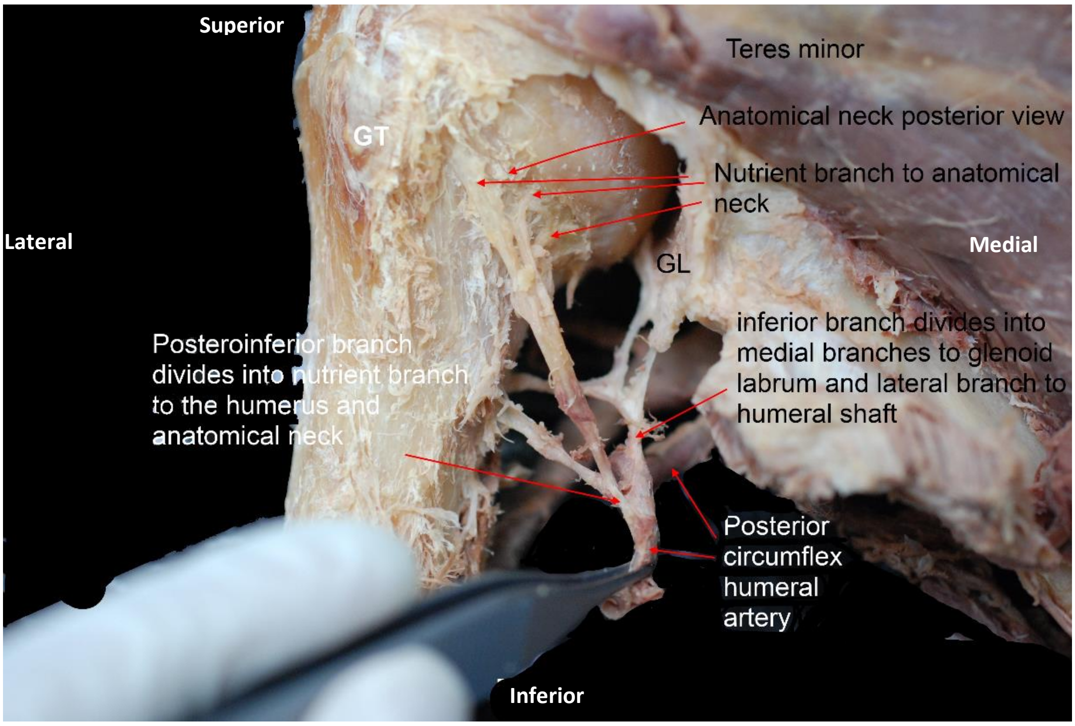


Figure 4.6.2: Posterior view of the left shoulder showing branches of the posterior circumflex humeral artery. GL: glenoid labrum; GT: greater tuberosity.

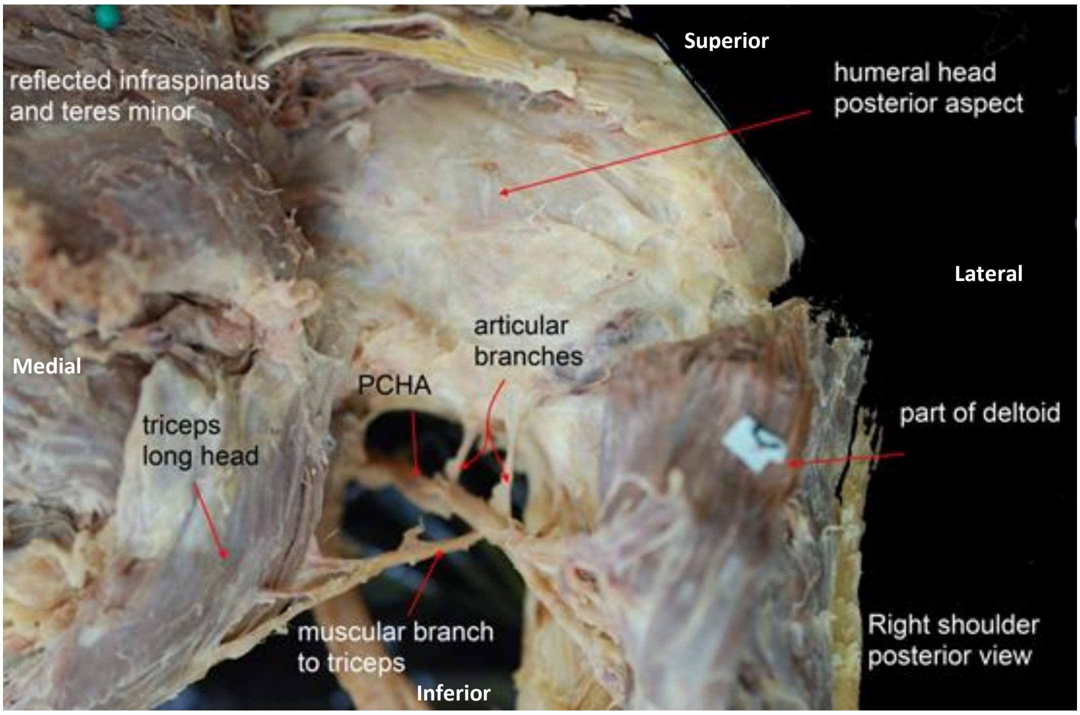


Figure 4.6.3: Posterior view of the left shoulder showing articular and muscular branches of the posterior circumflex humeral artery (PCHA).

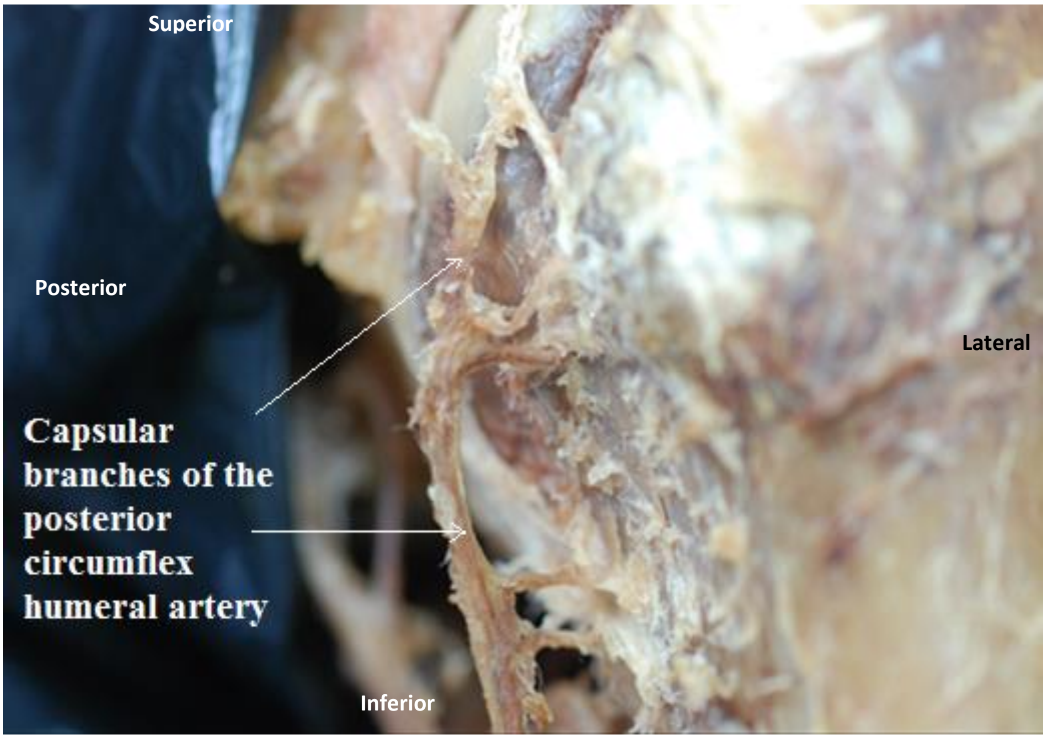


Figure 4.6.4: The posterior and posteroinferior capsular branches of the posterior circumflex humeral artery of the right shoulder supplying the surgical and anatomical necks.

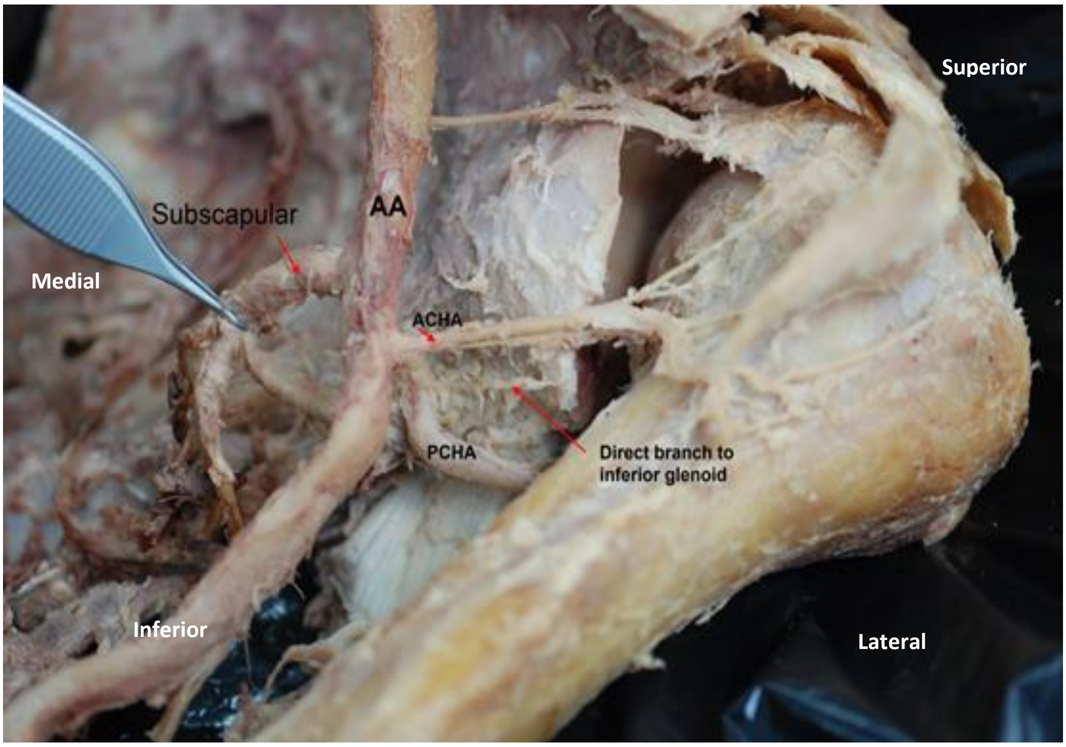


Figure 4.6.5: The left shoulder showing the inferior glenoid artery arising from the posterior circumflex humeral artery and supplying the glenoid labrum. AA: axillary artery; PCHA: posterior circumflex humeral artery; ACHA: anterior circumflex humeral artery.

4.7. Suprascapular artery

The suprascapular artery approached the superior border of the scapula with an overall diameter of 2.58mm. It passed over the transverse scapular ligament in 83.6% (n=117) of specimens with an average diameter of 2.61mm, while 16.4% (n=23) passed through the suprascapular notch with an average diameter of 2.41mm. The parameters of the suprascapular artery in both genders are summarized in Table 4.7.1. The suprascapular nerve and suprascapular vein passed through suprascapular notch. The suprascapular artery reached the supraspinous fossa and immediately passed lateral towards the shoulder joint. The main trunk continued its course going inferolateral to pass through the spinoglenoid notch lateral to the suprascapular nerve. It lay directly on the bone in the supraspinous fossa covered by loose of fatty tissue and supraspinatus. It passed through the spinoglenoid notch (covered by fibrous fatty tissues from its superior and inferior aspects) emerging into the infraspinous fossa where it ramified in infraspinatus and shared in the anastomoses around the scapula.

Branches:

I: Muscular to supraspinatus, infraspinatus and neighbouring muscles.

II: Small subscapular branch given off as the artery passed over the transverse scapular ligament; it descended into the subscapular fossa, ramified in subscapularis and gave periosteal branches to the subscapular fossa.

III: Articular:

To the acromioclavicular joint: when the suprascapular artery reached the spinoglenoid notch it gave two or three branches heading to the inferior aspect of the acromioclavicular joint.

To the shoulder joint:

Small branch: present in 85% (n=119) of specimens with a mean of length 36.40 and diameter of 1.16mm. It ran laterally posterior to the root of the coracoid process and parallel to the anterior aspect of the supraspinatus tendon passing through the distal aspect of supraspinatus and superior aspect of the fibrous capsule to supply the superior region of the glenoid labrum and origin of the long head of biceps. It gave periosteal branches at the superior aspect of the glenoid neck and nutrient branches to the superior aspect of the glenoid neck and the posterior part of the root of the coracoid process (Figures 4.7.1 – 4.7.3).

In the spinoglenoid notch: it gave two or more branches which pierced the joint capsule from the posterosuperior and posterior aspects. These supplied the posterior aspect of the tendon of supraspinatus (Figure 4.7.4).

IV: Nutrient artery: to the scapula at the superior region of the lateral end of the root of the spine of the scapula, supraspinous fossa, infraspinous fossa and to the inferior aspect of the acromion (Figure 4.7.1).

V: Periosteal branches: in the supraspinous fossa running towards the glenoid neck and some scattered in the infraspinous fossa.

Table 4.7.1: Comparison of the diameter of the suprascapular artery at the suprascapular notch.

Descriptive statistics	**Both genders**	**Males**	**Rt side males**	**Lt side males**	**Females**	**Rt side females**	**Lt side females**
	Diameter (mm)	**Diameter (mm)**	**Diameter (mm)**	**Diameter (mm)**	**Diameter (mm)**	**Diameter (mm)**	**Diameter (mm)**
Mean	2.58	2.70	2.67	2.72	2.50	2.5	2.5
Range	1.25 4.0	1.73 4.0	1.98 3.99	1.73 4.0	1.25 3.92	1.46 3.57	1.25 3.92
Standard deviation	0.57	0.57	0.54	0.60	0.57	0.54	0.60

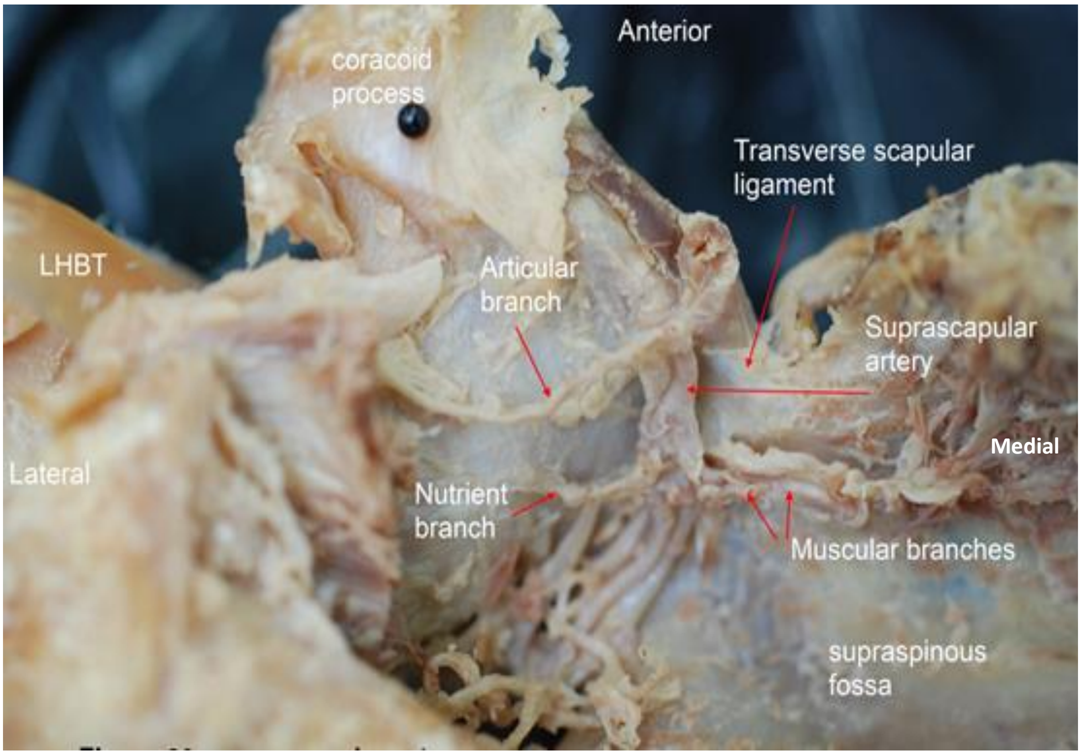


Figure 4.7.1: Superior view of the left supraspinous fossa showing the suprascapular artery and its branches. LHBT: long head of biceps tendon.

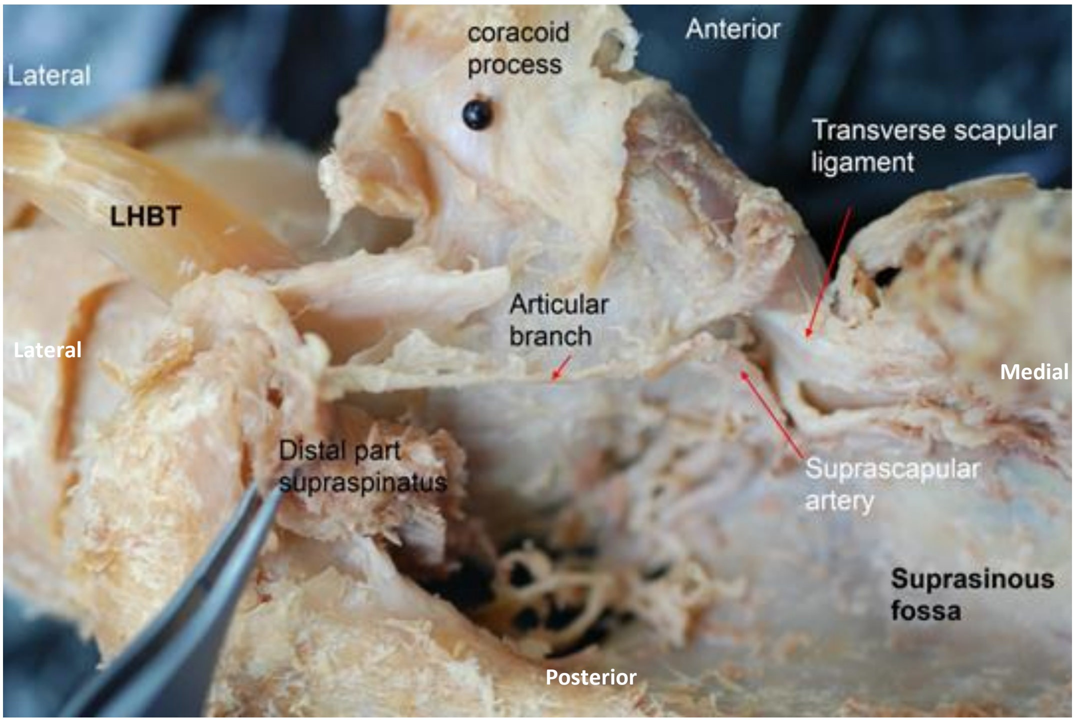


Figure 4.7.2: Superior view of the left supraspinous fossa showing the course of the articular branch of the suprascapular artery. LHBT: long head of biceps tendon.

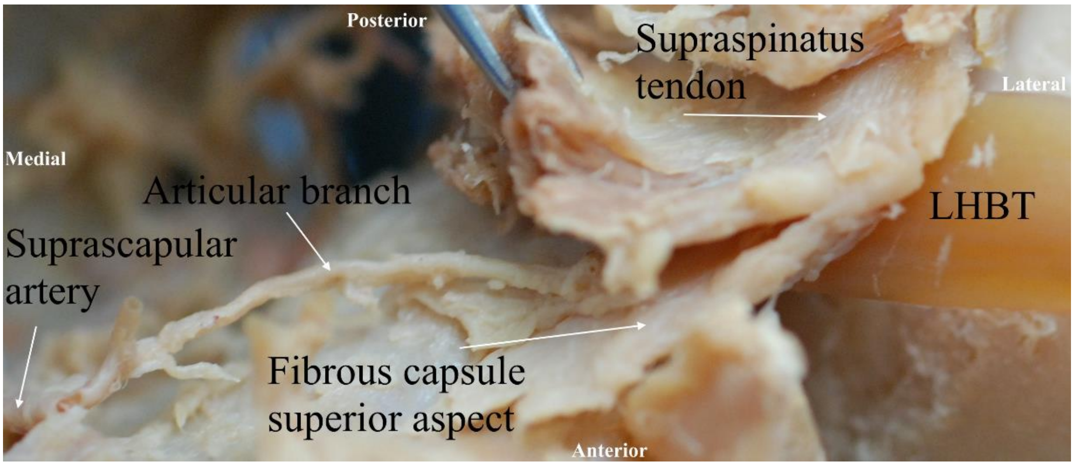


Figure 4.7.3: Superior view of the left shoulder showing the articular branch passing under the supraspinatus tendon and reaching the superior aspect of the glenohumeral joint. LHBT: long head of biceps tendon.

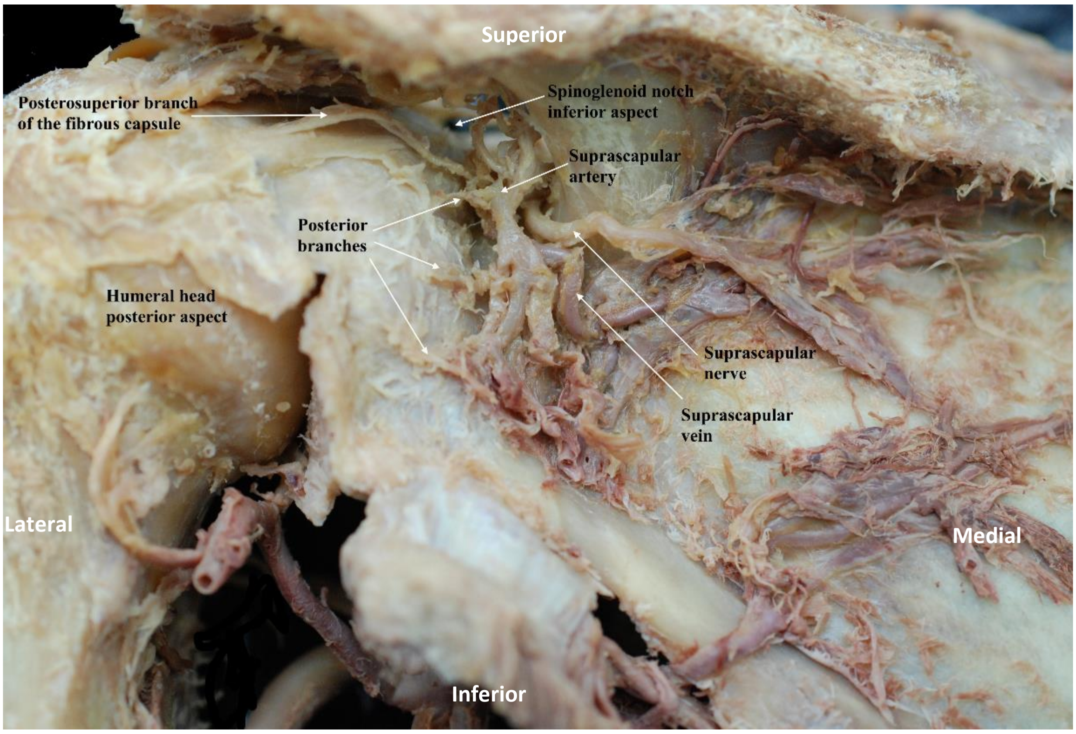


Figure 4.7.4: Posterior view of the left shoulder showing branches of the suprascapular artery.

In summary, the blood supply of the glenoid labrum by regions is as follows: the superior and anterosuperior regions receive their arterial supply from the ascending glenoid and suprascapular arteries as well as muscular branches from subscapularis andsupraspinatus; the anteroinferior and inferior regions receive their blood supply from periosteal branches of the circumflex scapular and inferior glenoid arteries, with the latter being a branch from either the posterior circumflex humeral, circumflex scapular or subscapular artery, as well as muscular branches from triceps and subscapularis. The posteroinferior and posterosuperior regions receive their arterial supply from periosteal branches from the suprascapular artery, muscular branches from teres minor and infraspinatus and occasionally an ascending branch from the circumflex scapular artery giving periosteal and direct branches to these regions as well as branches from the anterior and posterior circumflex humeral arteries which pierce the capsule anterosuperiorly, anteroinferiorly, inferiorly and posteroinferiorly supplying the anatomical neck, some of which also supply the labrum through the fibrous capsule (Figure 4.7.5).

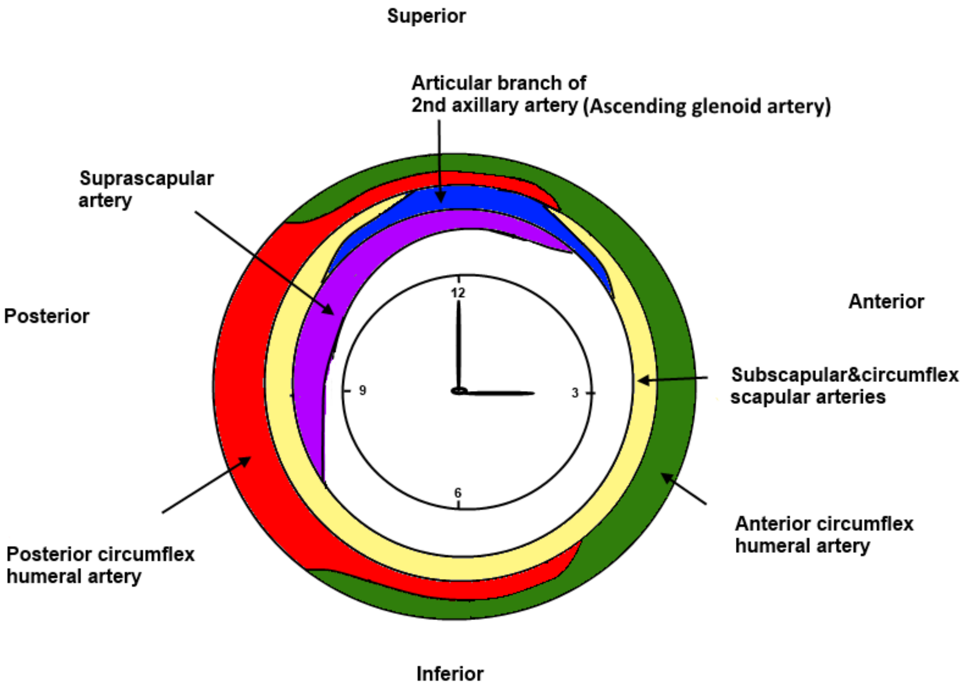


Figure 4.7.5. Summary of the blood supply of the glenoid labrum; the circle represents the glenoid labrum. The blue region is supplied by ascending glenoid artery; the green region is supplied by anterior circumflex humeral artery; the red region is supplied by posterior circumflex humeral artery; the purple region is supplied by suprascapular artery; and the yellow region is supplied by the subscapular and circumflex scapular arteries.

4.8. Common trunk origin

The axillary artery branches had a common origin in 36.42% (n=51) of specimens which arose from the lateral trunk of the axillary artery (3.92%, n=2), the brachial artery (3.92%, n=2), and the third part of the axillary artery (92.16%, n=47). Regardless of the origin of the trunk, its overall length was 5.92 mm and diameter 6.93 mm. The values for males and females are summarized Table 4.8.1. The trunk was longer in females but wider in males. Based on gender and side, the lengths and diameters of the common trunk origin were variable, being longer in males and wider in females, but the differences were not significant.

Table 4.8.1: Comparison of the mean length and diameter of the common origin trunk in males and females.

Descriptive statistics	Both genders		Males		Females	
	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)
Mean	5.9	6.9	5.1	7.7	6.3	6.5
Range	2.3 - 25.3	2.6 - 12.5	2.3 - 9.0	4.2 - 12.5	2.3 - 25.3	2.6 - 10.9
Standard deviation	3.82	2.27	1.91	2.42	4.51	2.11

Common trunk arising from the lateral trunk of the axillary artery:

The first part of the axillary artery of two females (one right, one left) divided into two trunks, lateral and medial. The medial trunk descended inferiorly as the brachial artery while the lateral trunk during its course in the axilla gave from its lateral side a common trunk, which was observed in 3.92% (n=2/51) of specimens (length 16.21 mm, diameter 6.31 mm). It gave rise to the profunda brachii, subscapular and anterior and posterior circumflex humeral arteries (Figures 4.8.1, 4.8.2).

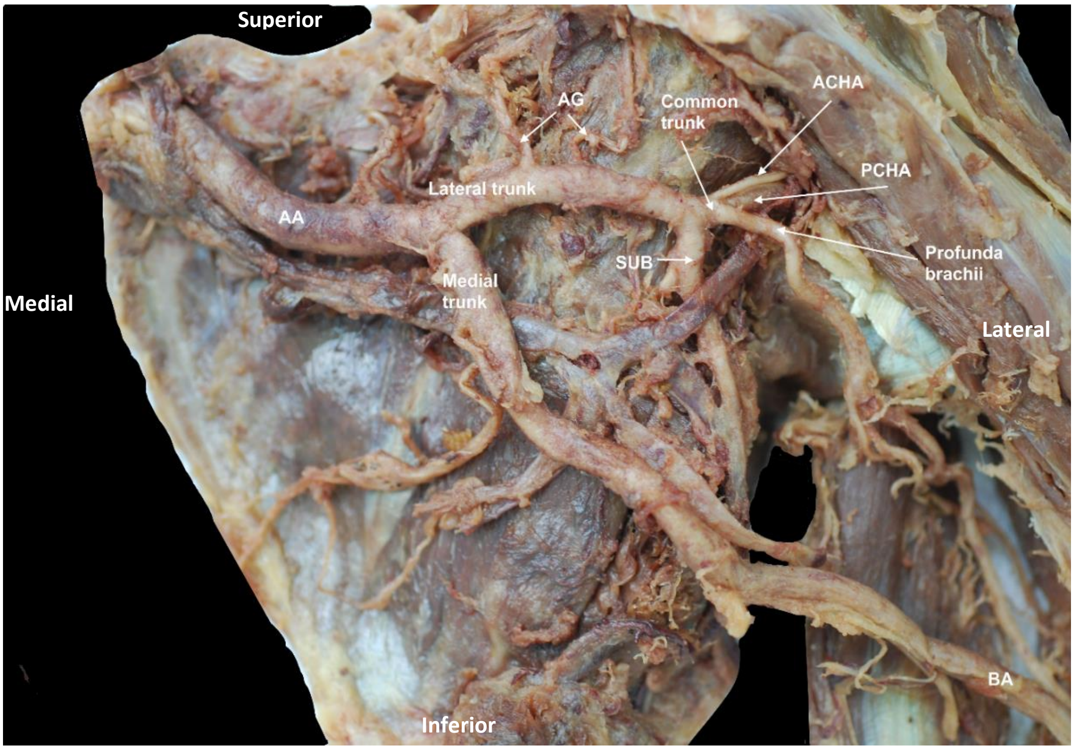


Figure 4.8.1: Anterior view of the left shoulder showing the axillary artery dividing into lateral and medial trunks. The lateral trunk gives a common trunk which divides into anterior circumflex humeral (ACHA), posterior circumflex humeral (PCHA) and profunda brachii (PB) arteries. The medial trunk becomes the brachial artery (BA).

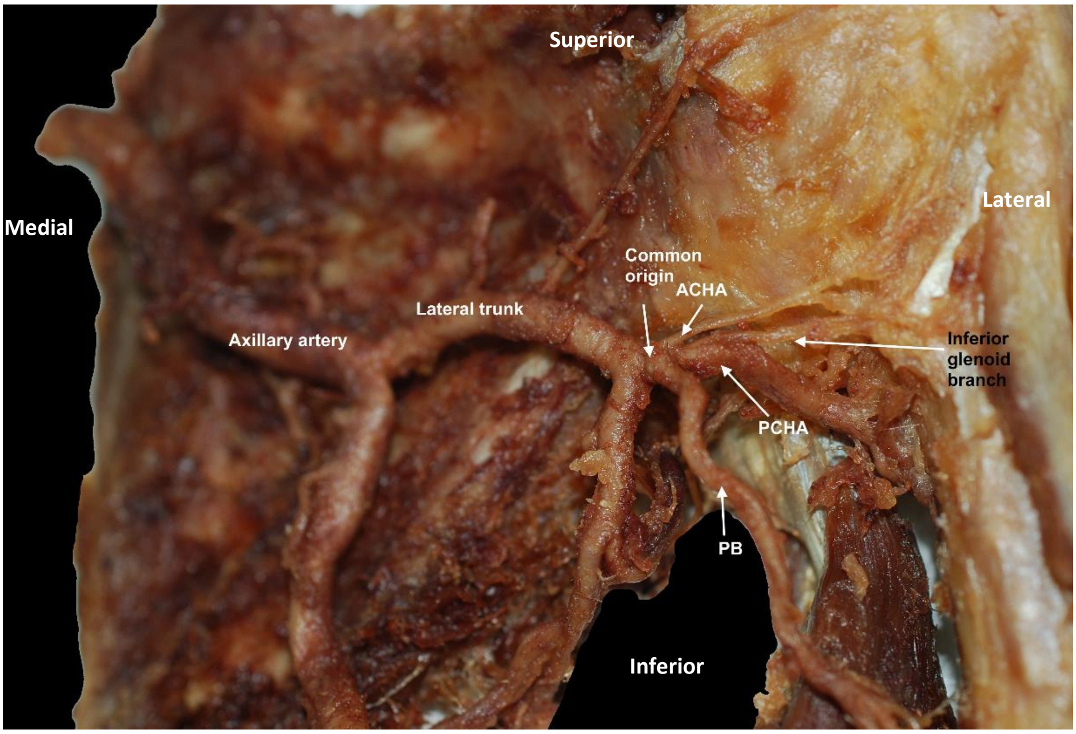


Figure 4.8.2: Anterior view of the left shoulder showing the axillary artery dividing into lateral and medial trunks. The lateral trunk gives a common trunk origin which divides into anterior circumflex humeral (ACHA), posterior circumflex humeral (PCHA) and profunda brachii (PB) arteries.

Common trunk arising from the brachial artery:

At the level of the mid arm the brachial artery gave a common trunk from its lateral side in 3.92% (n=2/51) of specimens with an average length and diameter of 6.73mm and 8.13mm. It gave origin to the profunda brachii, which followed its usual course, and the posterior circumflex humeral artery which ascended between the long and lateral heads of triceps to reach the posteroinferior aspect of the glenohumeral joint to ramify in deltoid (Figure 4.8.3).

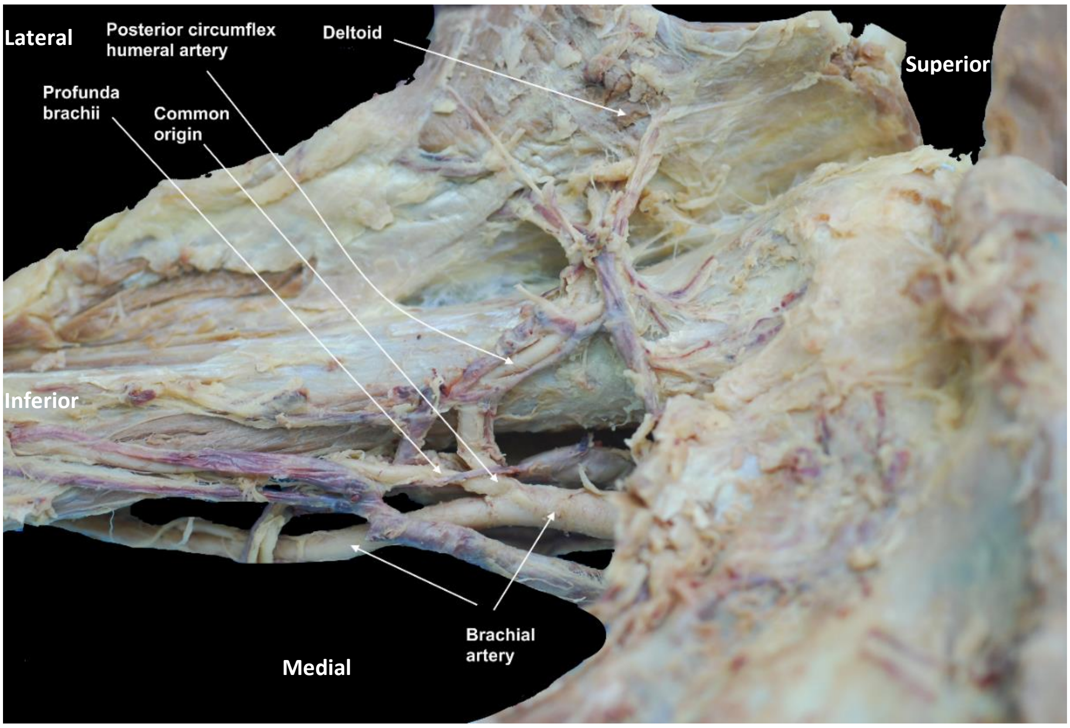


Figure 4.8.3: Posterior view of the left shoulder showing the common origin of the posterior circumflex humeral artery with the profunda brachii arising from the brachial artery.

Common trunk origin arising from the third part of the axillary artery:

The most frequent site of origin for a common origin trunk was the third part of the axillary artery: it was seen in 92.16% shoulders (n=47/51): its mean length was 5.45 mm and diameter 6.91 mm. It was longer in females but wider in males, but the differences were not significant (Table 4.8.2). The common origin gave rise to both the anterior and posterior circumflex humeral arteries (Figure 4.8.4), the posterior circumflex humeral and subscapular arteries (Figure 4.8.5), the posterior circumflex humeral and profunda brachii, the posterior circumflex humeral, subscapular and profunda brachii arteries (Figure 4.8.6 a, b), the posterior circumflex humeral and circumflex scapular arteries, the anterior circumflex humeral and subscapular arteries. The site of origin was variable being more common posteromedially and posterolaterally (Table 4.8.3).

Table 4.8.2: Length and diameter in males and females.

Descriptive statistics	Both genders		Males		Females	
	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)
Mean	5.4	6.9	5.0	7.52	5.7	6.6
Range	2.3 - 16.0	2.6 - 12.5	2.3 - 9.0	4.2 - 12.5	2.3 - 16.0	2.6 - 10.9
Standard deviation	2.72	2.30	1.84	2.42	3.11	2.19

Table 4.8.3: The site of origin of the common trunk arising from the 3rd part axillary artery; PL: posterolateral; PM: posteromedial; Post: posterior; Lat.: Lateral; Med.: medial; ACHA: anterior circumflex humeral artery; PCHA: posterior circumflex humeral artery; SUB: subscapular artery; PB: profunda brachii artery; CSA: circumflex scapular artery.

Site	ACHA & PCHA	PCHA & SUB	PCHA & PB	PCHA,SUB & PB	PCHA & CSA	ACHA & SUB
PL	12	4				1
PM	1	19			1	
Post.		3		1		
Lat.	2		1			
Med.		1		1		
Total	31.91%	57.44%	2.12%	4.25%	2.12%	2.12%

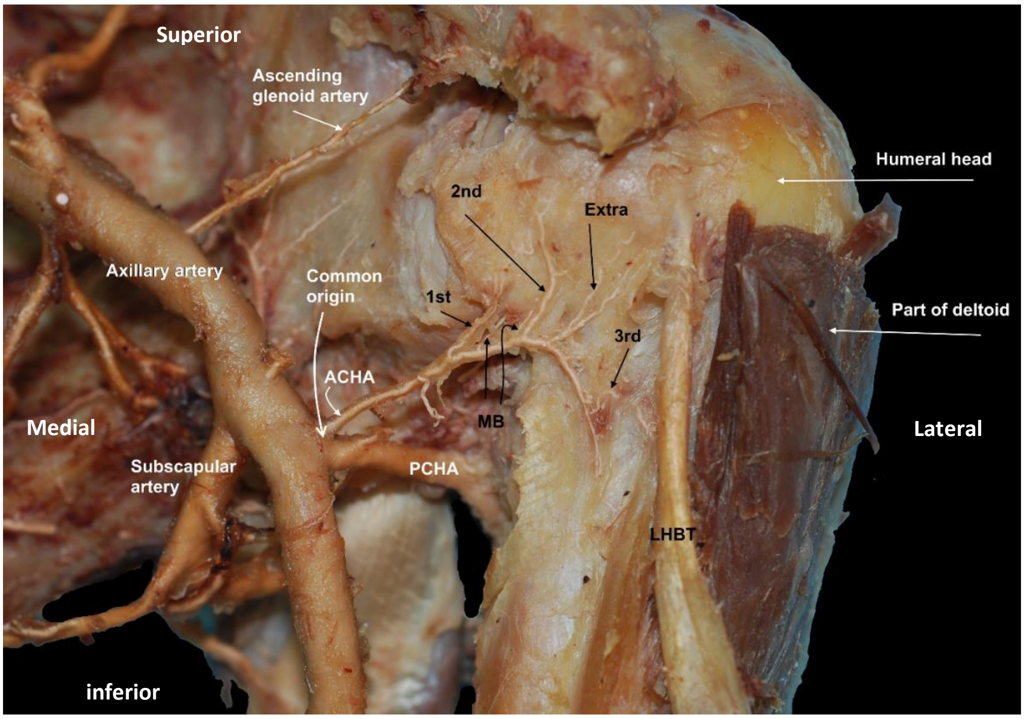


Figure 4.8.4: Anterior view of the left shoulder showing the common origin between the anterior circumflex humeral (ACHA) and posterior circumflex humeral arteries (PCHA).

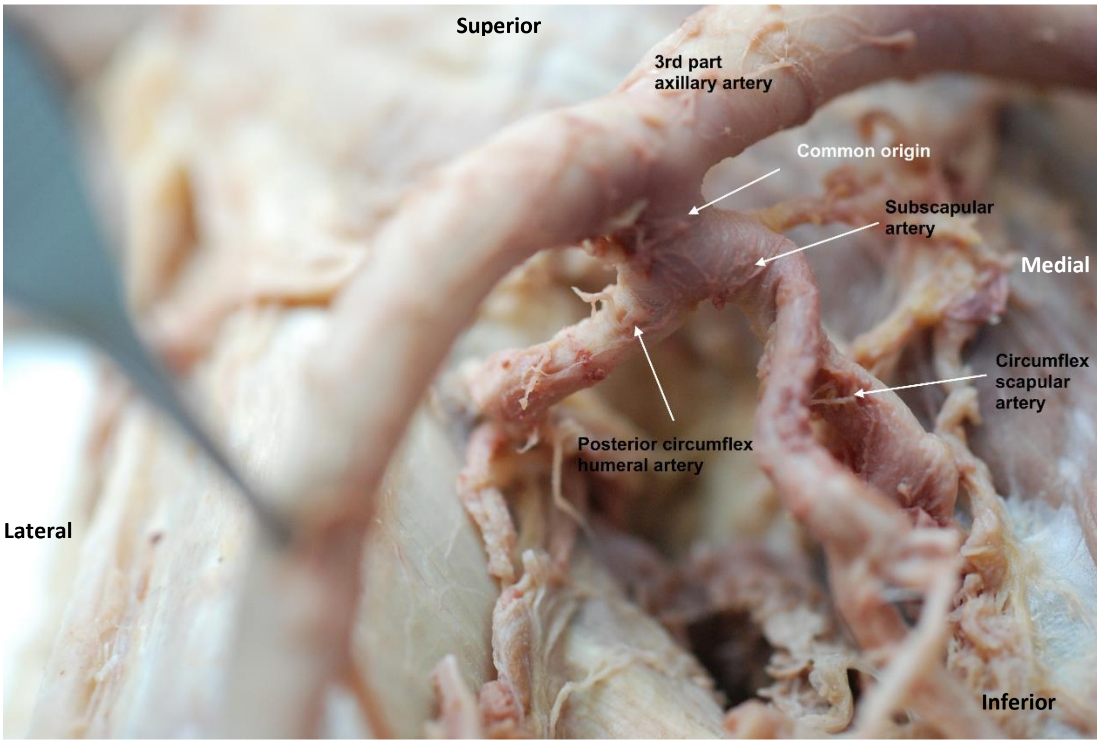


Figure 4.8.5: Posteromedial aspect of the right 3rd part of the axillary artery showing the common origin between the subscapular and posterior circumflex humeral arteries.

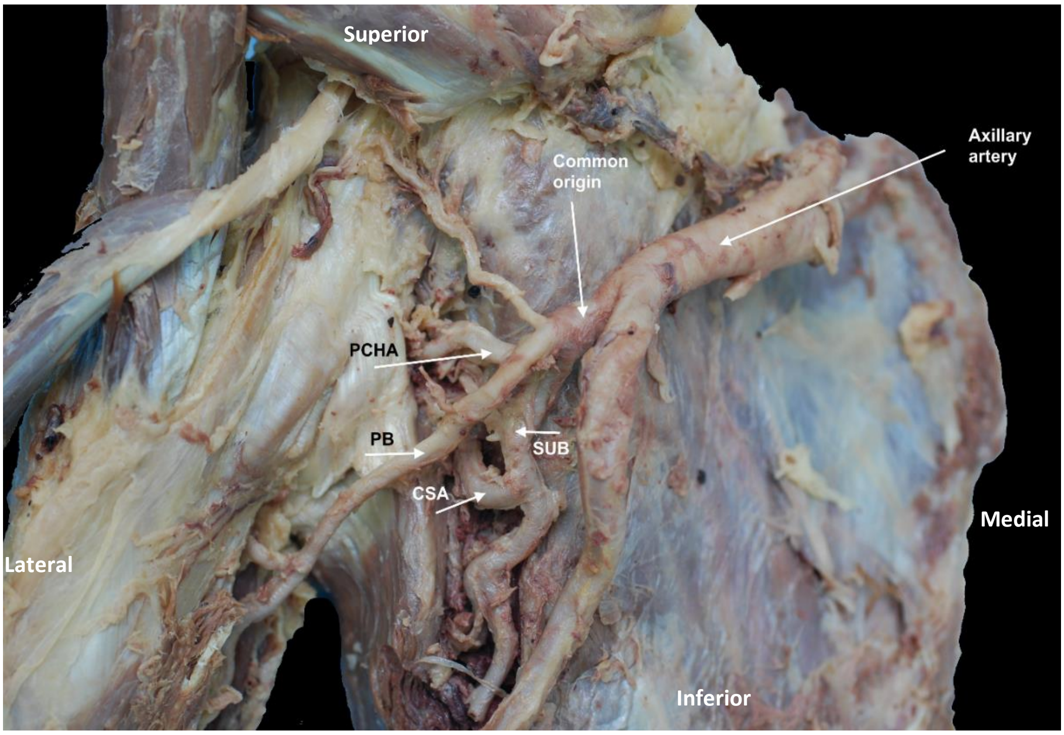


Figure 4.8.6A: Anterior view of the left shoulder showing the common orgin of subscapular (SUB), posterior circumflex humeral (PCHA) and profunda brachii (PB) arteries.

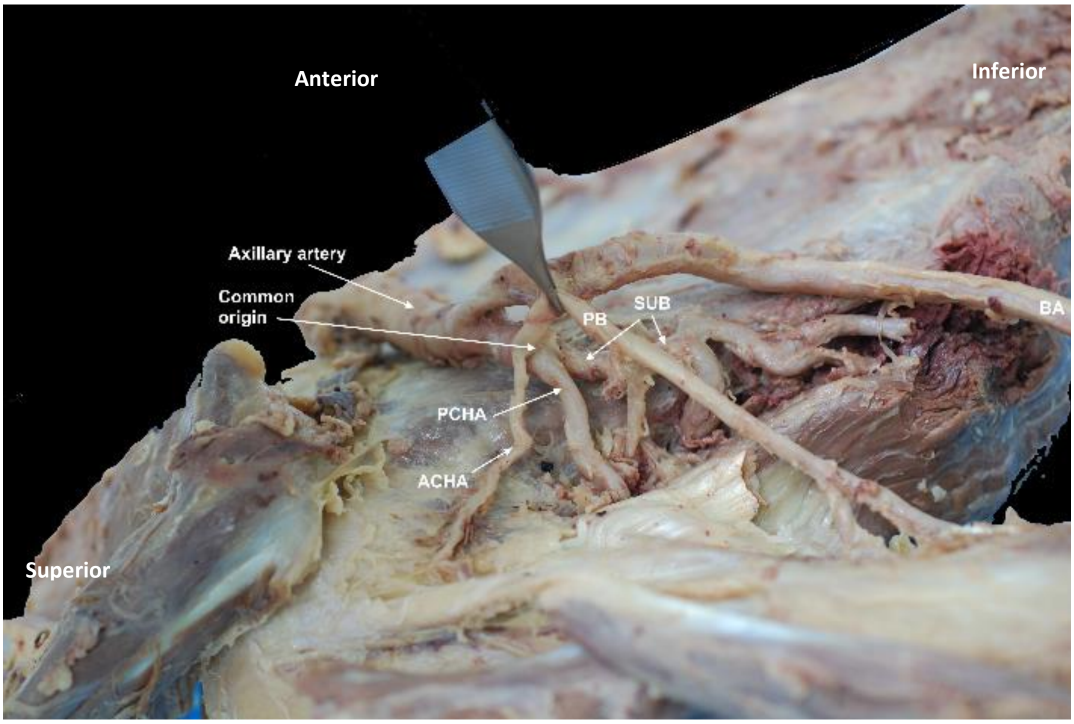


Figure 4.8.6B: Lateral view of the left shoulder showing the common orgin of subscapular (SUB), posterior circumflex humeral (PCHA) and profunda brachii (PB) arteries. ACHA: anterior circumflex humeral artery. BA: brachial artery.

4.9. Venous drainage

Venae Comitantes of the ascending glenoid artery

Venae comitantes accompanied the ascending glenoid artery and drained into the lateral vena comitante of the brachial artery, which later drained into the axillary vein. It received muscular veins from subscapularis, biceps brachii, coracobrachialis and the rotator cuff tendons in addition to veins accompanying capsular branches of the superior and anterosuperior aspect of the fibrous capsule, glenoid labrum and surrounding tissues (Figure 4.9.1).

Circumflex scapular and subscapular veins

Each branch of the circumflex scapular artery was accompanied by two vena comitante (sometimes one) which received veins from the infraspinous and supraspinous fossae, supraspinatus, teres minor and major, the long head of triceps, the inferior, posteroinferior and posterior aspect capsule veins and the surrounding tissues. The circumflex scapular veins drained directly into the subscapular vein accompanied by the thoracodorsal veins. The subscapular vein received the thoracocodorsal and circumflex scapular veins. It did not drain directly into the axillary vein (Figure 4.9.5) but united with other veins to form one vein which drained into the axillary vein (described in detail with the posterior circumflex humeral vein).

Anterior circumflex humeral veins

Two veins accompanied the anterior circumflex humeral artery in 96.42% (n=135) (Figure 4.9.2), a single common vein in 2.9% (n=4) and three veins in 0.7% (n=1). They ran from deltoid and winded around the surgical neck of the humerus to drain into the lateral vena comitante of the brachial artery (87.1%, n=122) (Figure 4.9.1), the posterior circumflex humeral vein (10%, n=14) or the axillary vein (2.9%, n=4). It had communicating veins with the posterior circumflex humeral veins in 93.57% (n=131). It received muscular veins from deltoid, teres major, latissimus dorsi, coracobrachialis, and biceps brachii, veins accompanying the ascending arteries (first, second and third) and nutrient veins from the anterior, anterolateral and lateral aspects of the humeral shaft (Figures 4.9.1, 4.9.2).

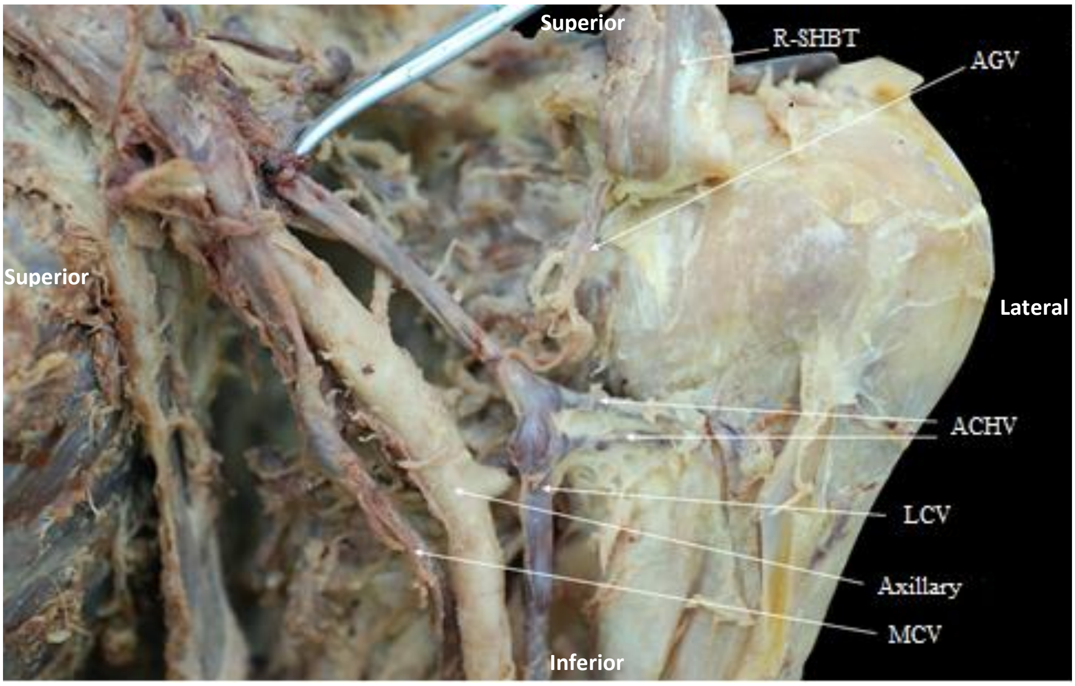


Figure 4.9.1: Anterior view of left shoulder showing anterior circumflex humeral veins (ACHV) and venae comitantes of the ascending glenoid artery (AGV) draining into the lateral vena comitante vein of the brachial artery (LCV). MCV: medial vena comitante of the brachial artery. R-SHBT: reflected short head of biceps tendon.

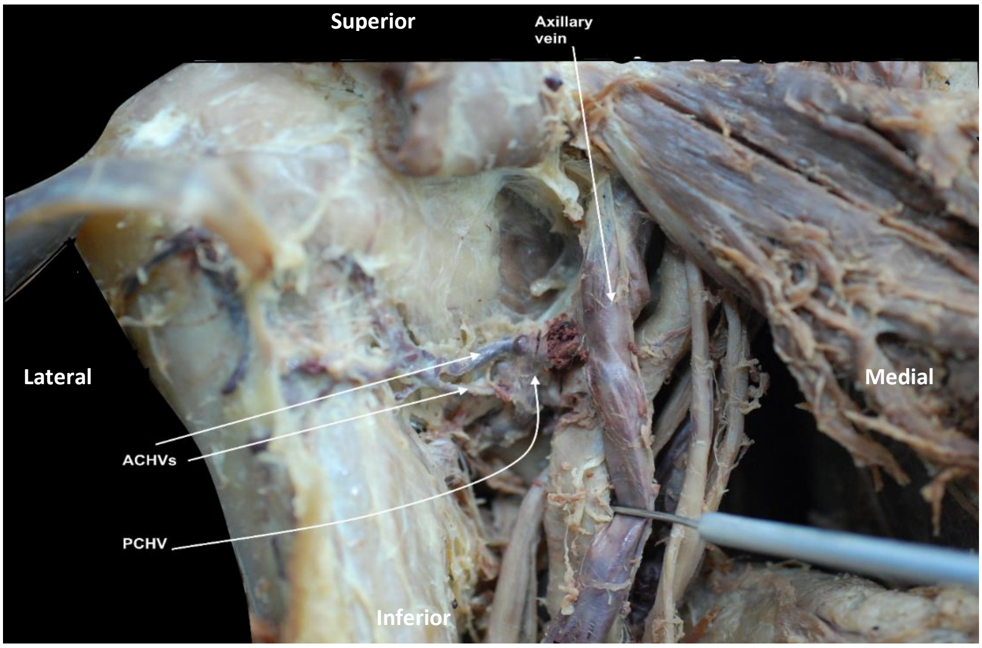


Figure 4.9.2: Anterior view of the left shoulder showing the anterior circumflex humeral veins (ACHVs) draining into the posterior circumflex humeral vein (PCHV) which in turn drain into the axillary vein.

Posterior circumflex humeral vein

The posterior circumflex humeral vein was found as one vein in 72.86% (n=102) and as two veins in 27.14% (n=38). It started inside deltoid and ran medially behind the surgical neck of the humerus accompanied by the anterior circumflex humeral artery and axillary nerve. It received anterior circumflex humeral veins (9.28%), muscular veins from deltoid, triceps, teres minor, subscapularis and adjacent muscles; veins from the head and anatomical and surgical necks of the humerus, besides the capsular and (occasionally) the inferior glenoid veins. It also received an ascending vein from the profunda brachii vein (95.71%, n=13) (Figure 4.9.3). The posterior circumflex humeral vein communicated with the anterior circumflex humeral veins (93.57%, n=131). In cases of two posterior circumflex humeral veins during their course around the surgical neck of the humerus they communicated with each other in a variable manner. It drained directly into the axillary vein as a single vein (0.7%, n=1), otherwise it united with the subscapular, circumflex scapular, medial vena comitante of the brachial artery and basilic veins (28.78%, n=40), subscapular and basilic veins (6.5%, n=9), subscapular and circumflex scapular veins (5.7%, n=8) subscapular vein (3.6%, n=5), subscapular, lateral concomitant of brachial and basilic veins (2.16%, n=3), subscapular, circumflex scapular, lateral and medial vena comitantes of the brachial artery, profunda brachii and basilic veins (4.3%, n=6), lateral vena comitante and basilic veins (2.9%, n=5), basilic vein (5%, n=7), subscapular, medial vena comitante of the brachial artery and basilic veins (21.7%, n=30), circumflex scapular and medial vena comitante of the brachial artery (2.16%, n=3), subscapular, circumflex scapular and medial vena comitante (4.3%, n=6), subscapular, circumflex scapular and basilic veins (9.3%, n=13), subscapular, circumflex scapular, medial vena comitante of brachial artery and profunda brachii (2.16%, n=3), subscapular and medical vena concomitante of brachial artery (1.44%, n=2). It drained into the axillary vein (75%, n=105), lateral vena comitante of the brachial artery (0.7%, n=1), medial vena comitante of the brachial artery (9.3%, n=13), basilic vein (15%, n=21) (Figures 4.9.2, 4.9.4, 4.9.5).

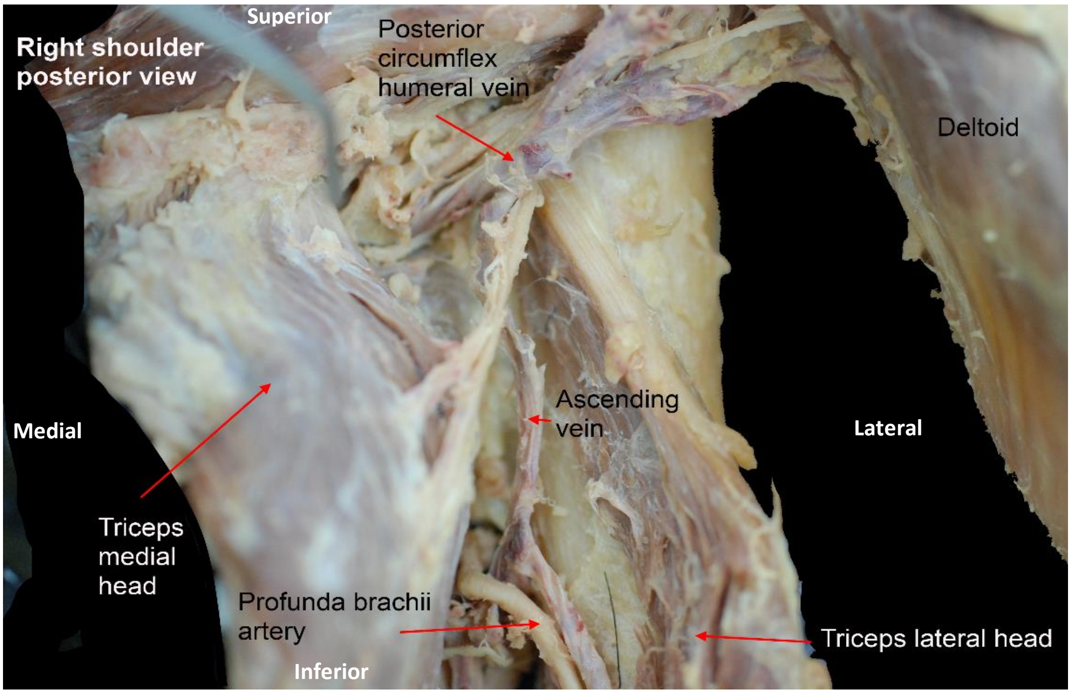


Figure 4.9.3: Posterior view of the right shoulder showing the posterior axillary vein winding around the surgical neck of the humerus and receiving the ascending vein of the profunda brachii artery.

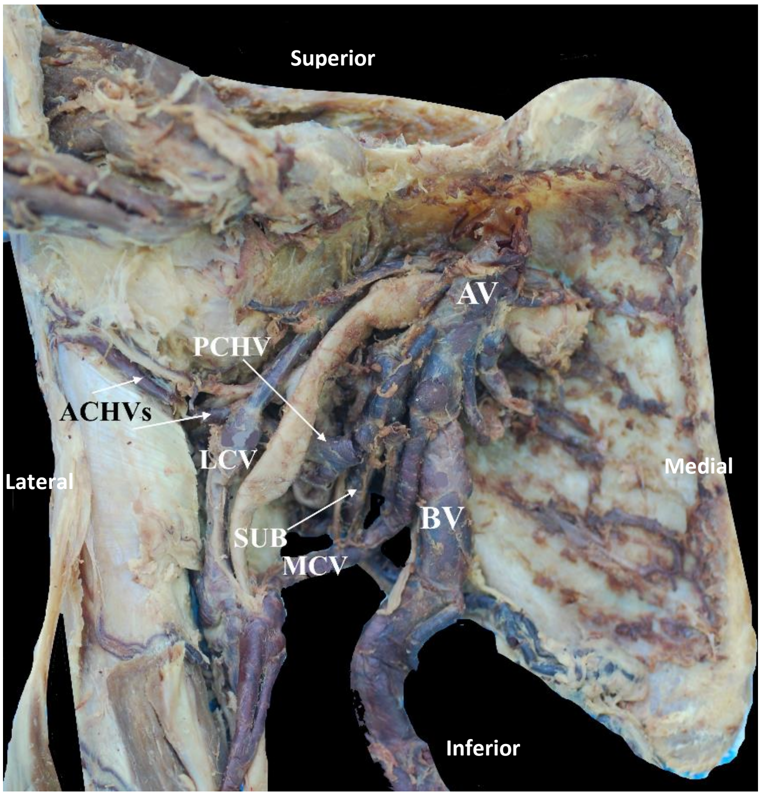


Figure 4.9.4: Anterior view of the right shoulder showing the anterior circumflex humeral veins (ACHVs), lateral vena comitante (LCV), medial vena comitante (MCV), posterior circumflex humeral vein (PCHV), subscapular vein (SUB), basilic vein (BV) and axillary vein (AV).

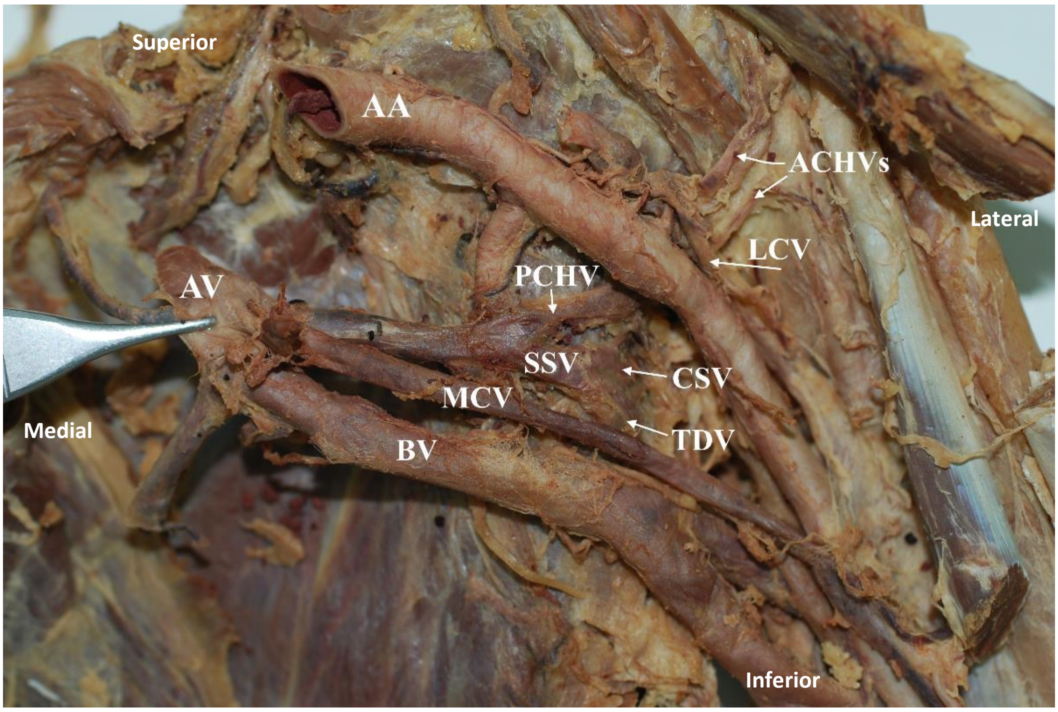


Figure 4.9.5: Anterior view of the left shoulder showing anterior circumflex humeral veins (ACHVs), posterior circumflex humeral vein (PCHV), circumflex scapular vein (CSV), thoracodorsal vein (TDV), subscapular vein (SSV), medial vena comitante of the brachial artery (MCV), lateral vena comitante of the brachial artery (LCV), basilic vein (BV), axillary vein (AV), and axillary artery (AA).

Part 2: Measurements of the glenoid labrum

4.10. Shape, consistency and thickness

Shape and consistency:

The superior half of the glenoid labrum was triangular in 95.72% (n=134), flat in 2.14% (n=3) and flat to triangular in 2.14% (n=3) of specimens, whereas the shape of the inferior half of the glenoid labrum was rounded in 99.29% (n=139) and flat in 0.71% (n=1) of specimens. The consistency of the superior half of the glenoid labrum was rubbery in 97.86% (n=137) and firm in 2.14% (n=3) of specimens, whereas the entire inferior half was firm.

Thickness:

Based on gender and side, the thickness of the glenoid labrum at 12, 3, 6 and 9 o'clock was variable. The thickest part was at 12 o'clock and thinnest at 3 o'clock (Table 4.10.1). There was a difference between males and females, being thicker in males in all the regions. The difference was significant at 12 o'clock (P=0.009), at 6 o'clock (P=0.003) and at 9 o'clock (P=0.005), but not at 3 o'clock (P=0.180). In females, at 12 and 9 o'clock the left glenoid labrum was thicker than the right side, whereas at 3 and 6 o'clock the right glenoid labrum was thicker than the left but the differences were not significant. The glenoid labrum was absent in two female right shoulders (1.42%) at 3 o'clock. In males, at 12 and 6 o'clock the thickness of the right and left glenoid labrum was the same, whereas the thickness of the left glenoid labrum at 3 o'clock was thicker than the right side and the thickness of the right glenoid labrum at 9 o'clock was thicker than the left side: these differences were not significant (Tables 4.10.2 and 4.10.3).

Table 4.10.1: Thickness of the glenoid labrum in both genders.

Descriptive statistics	**Both genders**			
	At 12	At 3	At 6	At 9
Mean (mm)	6.01	3.93	5.13	4.29
Range (mm)	2.9 8.78	1.5 7.91	2.13 8.83	2.08 6.99
Standard deviation (mm)	1.12	0.98	1.09	1.01

Table 4.10.2: Thickness of the glenoid labrum in females. SD: standard deviation.

Descriptive statistics	**Overall in females**				**Right side**				**Left side**			
	At 12	At 3	At 6	At 9	At12	At 3	At 6	At 9	At12	At 3	At 6	At 9
Mean (mm)	5.80	3.83	4.90	4.08	5.67	3.93	4.91	4	5.92	3.71	4.89	4.14
Range (mm)	2.90 6.99	2.04 6.11	2.52 8.12	2.08 5.82	2.90 8.01	2.67 5.59	3.26 8.12	2.66 5.82	3.12 8.46	2.04 6.11	2.52 8.05	2.08 5.51
SD (mm)	1.10	0.80	0.96	0.86	1.16	0.75	0.95	0.89	1.07	0.83	1	0.84

Table 4.10.3: Thickness of the glenoid labrum in males. SD: standard deviation.

Descriptive statistics	**Overall in males**				**Right side**				**Left side**			
	At 12	At 3	At 6	At 9	At12	At 3	At 6	At 9	At12	At 3	At 6	At 9
Mean (mm)	6.28	4.04	5.40	4.53	6.29	3.99	5.40	4.66	6.27	4.09	4.40	4.39
Range (mm)	3.88 8.78	1.5 7.91	2.13 8.83	2.28 6.99	3.88 8.78	1.86 7.91	2.79 8.83	2.28 6.99	4.31 8.53	1.5 7.1	2.13 7.49	2.93 6.63
SD (mm)	1.09	1.17	1.15	1.11	1.16	1.17	1.21	1.15	1.03	1.19	1.09	1.07

4.11. Depth of the glenoid labrum

Based on gender and side, the depth of the glenoid labrum at 12, 3, 6 and 9 o'clock was variable. The deepest part of the glenoid labrum was at 12 o'clock and the shallowest region was at 3 o'clock (Table 4.11.1). There was a difference in depth between males and females, being deeper in males in all regions: the differences were significant at 12 o'clock (P=0.002) and 6 o'clock (P=0.010), but not at 3 and 9 o'clock (P=0.552 and P=0.535 respectively). In females, the depth of the right side at regions 12, 3 and 6 o'clock was greater in comparison to the corresponding regions of the left side, which was only significant at 3 o'clock (P=0.011), whereas the depth was greater on the left side at the region of 9 o'clock than that of the right side, but was not significant

(P=0.103). The glenoid labrum was absent in two female right shoulders (1.42%) at the 3 o'clock region. In males, the depth of the left side glenoid labrum at the regions of 12, 3 and 6 o'clock was greater in comparison to the corresponding regions of the right side, whereas the depth was more on the right side at the region of 9 o'clock than that of the left side (Tables 4.11.2 and 4.11.3): the differences were not significant.

Table 4.11.1: Depth of the glenoid labrum in both genders.

Descriptive statistics	**Both genders**			
Site	At 12	At 3	At 6	At 9
Mean (mm)	5.95	3.63	3.73	3.84
Range (mm)	3.36 8.73	0.72 5.51	1.72 5.43	2.46 5.72
Standard deviation (mm)	0.98	0.71	0.65	0.63

Table 4.11.2: Depth of the glenoid labrum in females; SD: standard deviation; Rt: Right, Lt: left.

Descriptive statistics	**Overall in females**				**Right side**				**Left side**			
	At 12	At 3	At 6	At 9	At 12	At 3	At 6	At 9	At 12	At 3	At 6	At 9
Mean (mm)	5.73	3.60	3.61	3.81	5.62	3.78	3.62	3.68	3.83	3.44	3.61	3.93
Range (mm)	3.36 7.8	2.23 5.51	2.07 4.84	2.46 5.72	3.36 7.77	2.23 5.51	2.09 4.84	2.7 5.72	4.05 7.8	2.34 4.75	2.07 4.7	2.46 5.4
SD (mm)	0.93	0.61	0.61	0.69	0.95	0.57	0.61	0.64	0.91	0.60	0.62	0.73

Table 4.11.3: Depth of the glenoid labrum in males. SD: standard deviation.

Descriptive statistics	**Overall in males**				**Right side**				**Left side**			
	At12	At 3	At 6	At 9	At12	At 3	At 6	At 9	At12	At 3	At 6	At 9
Mean (mm)	6.24	3.68	3.90	3.88	6.10	3.62	3.85	3.90	6.42	3.71	3.97	3.84
Range (mm)	4.05 8.73	0.72 5.44	1.72 5.43	2.66 5.22	4.05 7.65	0.72 5.44	1.72 4.9	3.02 4.68	4.32 8.73	1.89 5.11	2.62 5.43	2.66 5.22
SD (mm)	0.96	0.83	0.66	0.53	0.91	0.90	0.67	0.43	1	0.76	0.65	0.62

4.12. Sublabral foramen

A sublabral foramen is defined as detachment of the anterosuperior aspect of the glenoid labrum from the underlying articular surface (Figure 4.12.1). It was only seen in 40 (28.57%) shoulders, being slightly more in males (21 shoulders) than females (19 shoulders). It was also more common on the right side than the left in both genders (Table 4.12.1).

Table 4.12.1: Comparison of the sublabral foramen in both genders.

Availability	Females	Rt side females	Lt side females	Males	Rt side males	Lt side males
28.57%	26.25%	13.75%	12.5%	31.66%	18.33%	13.33%

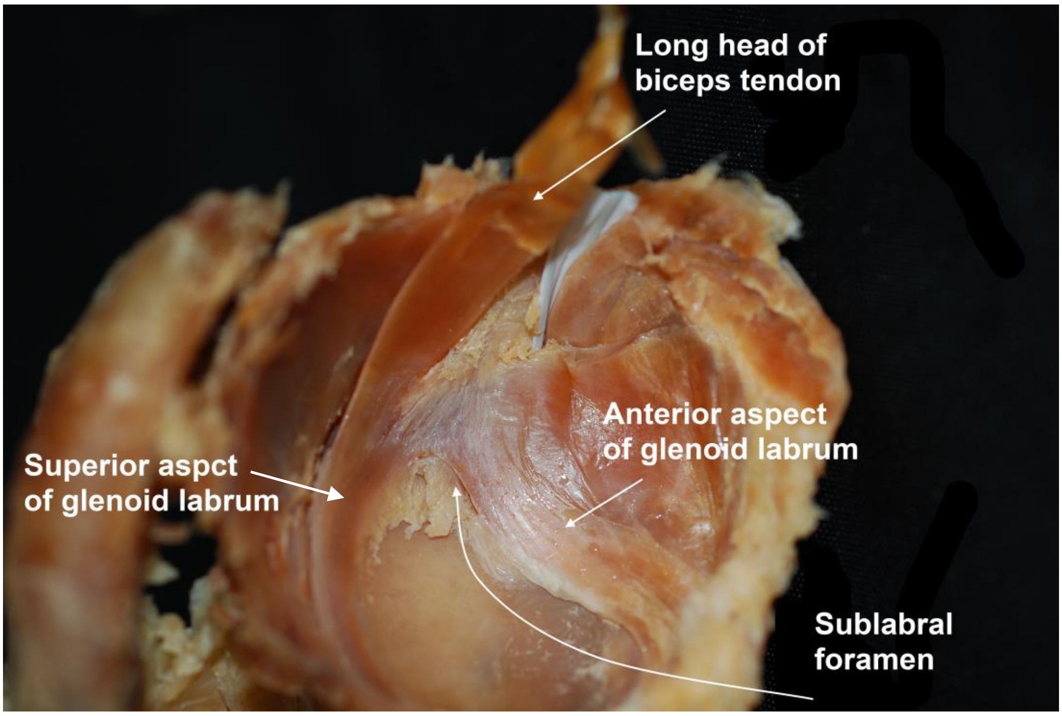


Figure 4.12.1: Right shoulder showing a sublabral foramen.

4.13. Buford complex

The Buford complex, which is the absence of the anterosuperior aspect of the glenoid labrum and the middle glenohumeral ligament is a cord-like structure, was only found in one (1.42%, n=2) female cadaver but on both sides.

4.14. Long head of biceps attachment

Based on the classification of Vangsness et al. (1994) (see Figure 3.25) the following types were observed. Type I, in which all fibres attached posteriorly was the most common and seen in 62 shoulders, being more common in males than females (31/60 male shoulders and 31/80 female shoulders). In males it was observed to be more common on the right side, whereas in females it was more common on the left side. Type II, in which most fibres attach posteriorly with some anteriorly, was the second most common type and seen in 41 shoulders, being more common in females (28 shoulders). In males it was observed to be slightly more common on the left side, whereas in females it was more common on the right side. Type III, in which there is equal distribution, was seen in 21 shoulders and was more common in males than females. In males, it was more common on the left side, while in females it was more common on the right side. Type IV, in which most fibres attach anteriorly with some posterior, was only seen in 6 shoulders, being more common in males and on the right side in both genders.

The long head of biceps was completely degenerated in 10 shoulders (Figure 4.14.1) and was attached to the superior aspect of the fibrous capsule instead. It was more common in females (8 shoulders) than males (2 shoulders). In females, it was double the incidence on the right side than the left, while in males it was only on the left side (Table 4.14.1).

Table 4.14.1: Classification (%) of the long head of biceps attachment.

Type	Both genders overall	Females	Rt side females	Lt side female	Males	Rt side males	Lt side male
Type I:	44.29	38.75	13.75	25	51.66	28.33	23.33
Type II:	29.29	35	20	15	21.66	10	11.66
Type III:	15	12.5	7.55	5	18.33	8.33	10
Type IV:	4.28	3.75	2.5	1.25	5	3.33	1.66
Degenerated	7.14	10	6.25	3.75	3.33	0	3.33

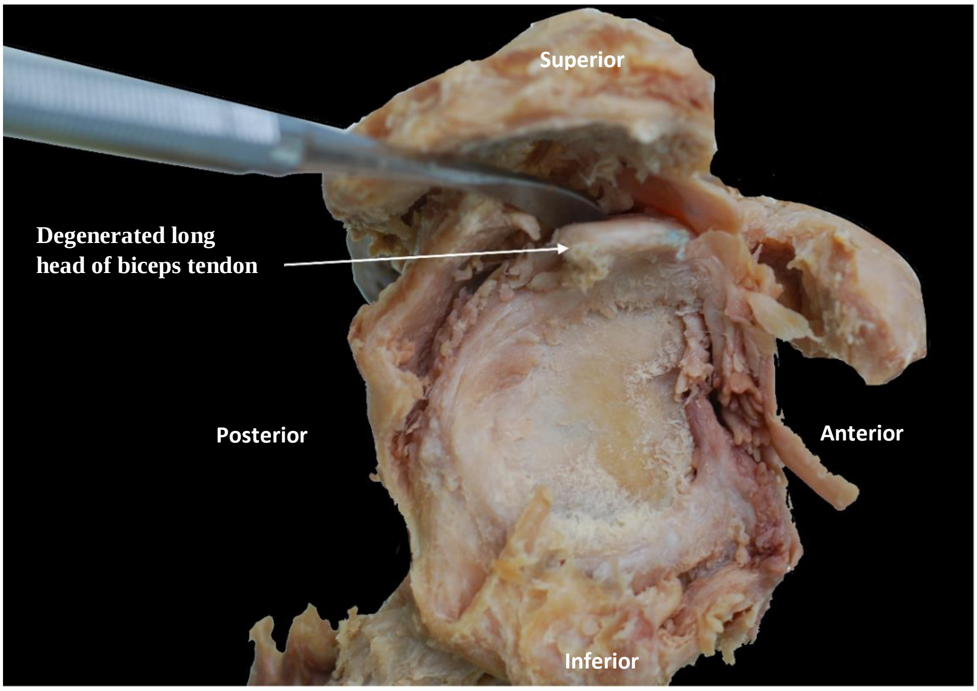


Figure 4.14.1: Right shoulder showing degenerated long head of biceps tendon

4.15. Shape of the glenoid fossa

The shape of the glenoid fossa was oval in 42 shoulders and pear-shaped in 98 shoulders (Figure 4.15.1). The oval shaped glenoid was more common in females (34 shoulders) than males (8 shoulders), whereas the pear-shaped glenoid was more common in males (52 shoulders) than females (46 shoulders). According to side, oval and pear-shaped glenoids were equal on the right and left sides in both genders (Table 4.15.1).

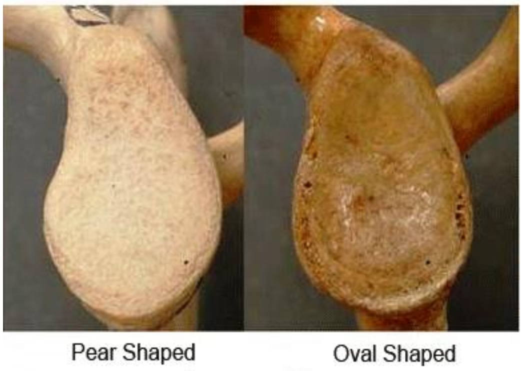


Figure 4.15.1: Types of the shape of the glenoid fossa

Table 4.15.1: Shape of the glenoid fossa in males and females.

Type	Both genders overall	Females	Rt side females	Lt side female	Males	Rt side males	Lt side male
Oval (%)	30	42.5	21.25	21.25	13.33	6.66	6.66
Pear (%)	70	57.5	28.75	28.75	86.66	43.33	43.33

4.16. Glenoid notch

A glenoid notch can be classified into three types, mild (I), moderate (II) and severe (III) (Figure 4.16.1). Type III was the most commonly observed (53 shoulders), followed by type I (48 shoulders) and then type II. Type I was more common in females (34 shoulders) than males (14 shoulders), being equally distributed between right and left sides, while in males it was more common on the right side. Type II was also more common in females (39 shoulders) than males (14 shoulders), being equally distributed between right and left sides in males and more common on the left side females. On the other hand type III was almost twice as common in males (32 shoulders) than females (21 shoulders). In females, it was more common on the right side, while in males in was more common on the left side (Table 4.16.1).

Figure 4.16.1: Types of the glenoid notch. Type I: mild; type II: moderate; type III: severe.

Table 4.16.1: Shape of the glenoid notch in males and females.

Type	Both genders overall	Females	Rt side females	Lt side females	Males	Rt side males	Lt side males
Type I (%)	34.28	42.5	21.25	21.25	23.33	13.33	10
Type II (%)	27.86	31.25	15	16.25	23.33	11.66	11.66
Type III (%)	37.86	26.25	13.75	12.5	53.33	25	28.33

4.17. Glenohumeral ligaments

Superior glenohumeral ligament

The superior glenohumeral ligament arose from the anterosuperior aspect of the glenoid labrum between the long head of the biceps attachment and the middle glenohumeral ligament (Figure 4.17.1) and ran laterally to attach to the anterior aspect of the humerus. Its overall mean thickness in both genders at its origin was 5.06 mm; however its mean thickness was greater in males that females, but not significantly so (P=0.223). In males, the left side was thicker than the right, whereas in females the left side was thicker than the right (Table 4.17.1). In both genders, the difference in mean thickness between sides was not significant.

Table 4.17.1: Thickness of the superior glenohumeral ligament (SGHL) in both genders; SD: standard deviation.

SGHL	Both genders overall	Females	Rt side females	Lt side female	Males	Rt side males	Lt side male
Mean thickness (mm)	5.06	4.97	4.82	5.12	5.17	5.02	5.33
Range (mm)	2.52 8.89	2.89 8.89	2.89 6.69	3.26 8.89	2.52 7.84	3.25 6.5	2.52 7.84
SD (mm)	0.93	0.93	0.76	1.06	1.02	0.83	1.17

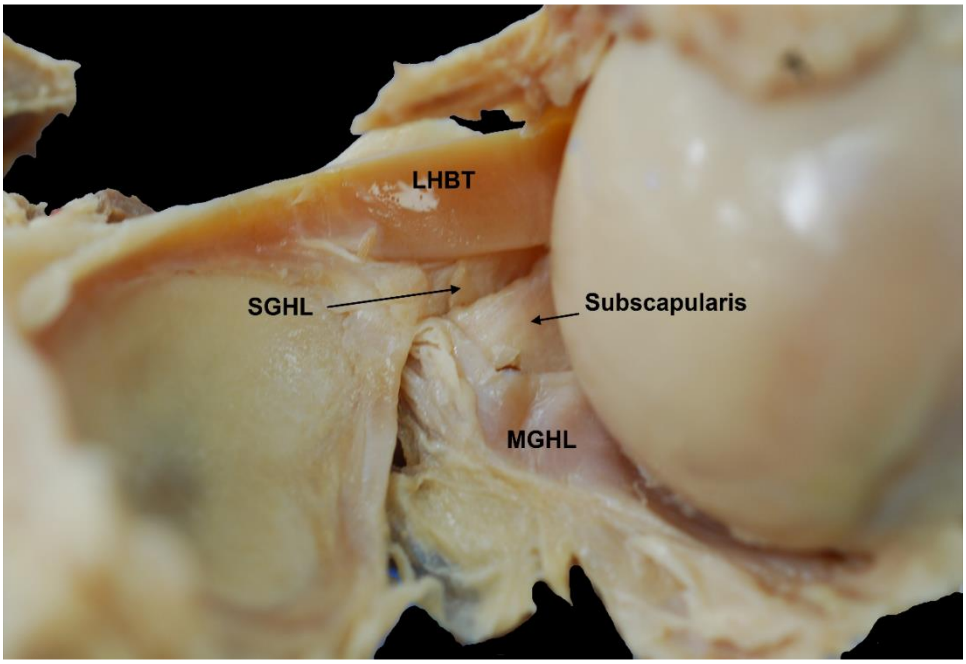


Figure 4.17.1: Right shoulder showing the superior (SGHL) and middle glenohumeral (MGHL) ligaments; LHBT: long head of biceps tendon.

Middle glenohumeral ligament:

The middle glenohumeral ligament was found in 98.57% (n=138) of specimens arising from the anterior aspect of the glenoid labrum immediately inferior to the superior glenohumeral ligament (Figures 4.17.1 - 2): less frequently it arose more medially along the neck of scapula. It was often redundant at the site of origin. It ran laterally to attach to the anterior aspect of the humerus just inferior to the superior glenohumeral ligament. The overall mean thickness of the middle glenohumeral ligament at its origin in both genders was 5.97 mm. The mean thickness was greater in males than females: the difference being statistically significant (P=0.003). In both genders, the right middle glenohumeral ligament was thicker than the left side one, but the difference was not significant (Table 4.17.2). The middle glenohumeral ligament was absent in one (1.42%) female cadaver on both sides.

Table 4.17.2: Thickness of the middle glenohumeral ligament (MGHL) in both genders; SD: standard deviation.

MGHL	Both genders overall	Females	Rt side females	Lt side female	Males	Rt side males	Lt side male
Mean thickness (mm)	5.97	5.67	5.74	5.60	6.36	6.40	6.32
Range (mm)	1.75 11.17	3.09 7.58	3.09 7.58	3.2 7.45	1.75 11.17	3.49 8.4	1.75 11.17
SD (mm)	1.35	1.15	1.23	1.08	1.50	1.27	1.72

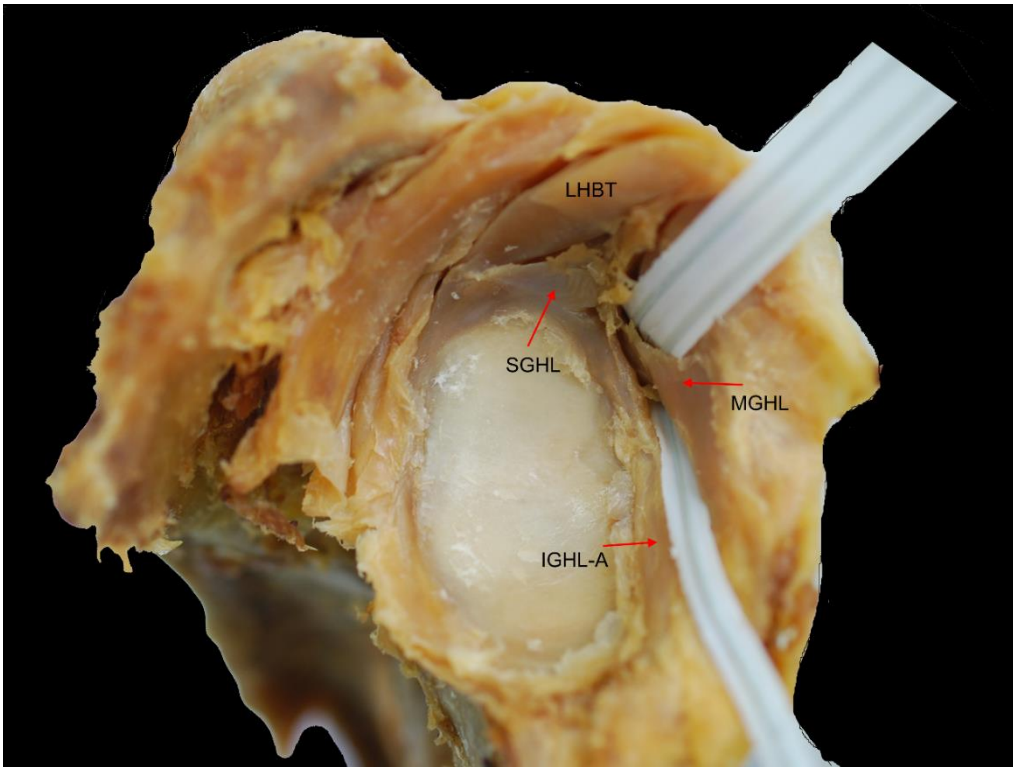


Figure 4.17.2: Right shoulder showing the superior (SGHL), middle (MGHL) and inferior glenohumeral anterior band (IGHL-A) ligaments; LHBT: long head of biceps tendon.

Inferior glenohumeral ligament anterior band

The inferior glenohumeral ligament anterior band arose from the anteroinferior aspect of the glenoid labrum between 3 and 5 o'clock and ran laterally to attach to the anteroinferior aspect of the humerus (Figure 4.17.2). The overall mean thickness of the inferior glenohumeral ligament anterior band at its origin in both genders was 4.41 mm.

The mean thickness was greater in males than females: the difference was significant (P=0.052). It was also thicker on the left side than the right side in both genders, but the differences were not significant Table (4.17.3).

Table 4.17.3: Thickness of the inferior glenohumeral ligament anterior band (IGHL-A) in both genders; SD: standard deviation.

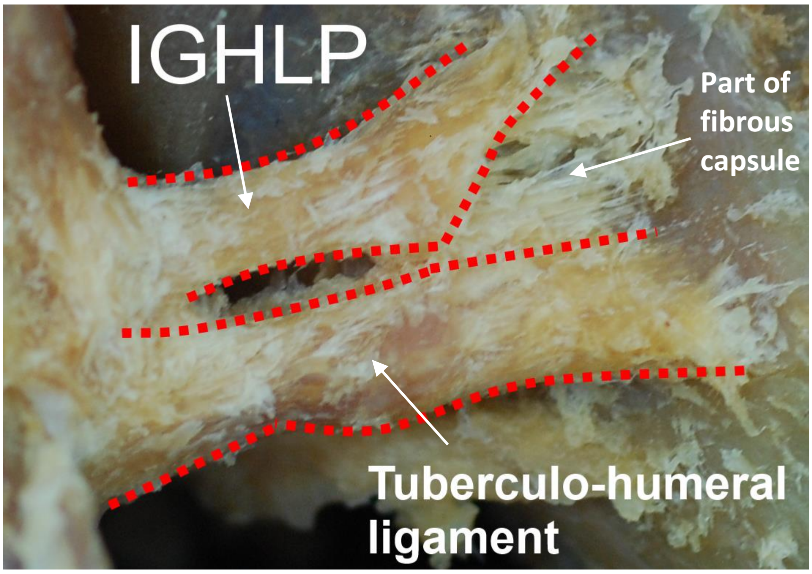
IGHL-A	Both genders overall	In females	Rt side females	Lt side female	In males	Rt side males	Lt side male
Mean thickness (mm)	4.41	4.23	4.08	4.37	4.67	4.60	4.73
Range(mm)	1.54 8.1	1.54 8.1	2.01 6.85	1.54 8.1	1.76 8.05	1.76 7.25	1.88 8.05
SD (mm)	1.33	1.23	1.13	1.32	1.42	1.45	1.41

Inferior glenohumeral ligament posterior band

An inferior glenohumeral ligament posterior band was present in 79.28% (n=111) of specimens arising from the posteroinferior aspect of the glenoid labrum between 7 and 9 o'clock, running laterally to attach to the posteroinferior aspect of the humerus to form, with the anterior band of the inferior glenohumeral ligament, the axillary pouch (Figure 4.17.3). The overall mean thickness of the inferior glenohumeral ligament posterior band at its origin of both genders was less than the anterior band, being 3.45 mm, with the mean thickness being greater in males than females: the difference was statistically significant (P=0.004). In males, the right side was thicker than the left, while in females the left side was thicker than the right: the differences however were not significant (Table 4.17.4). It was absent in 29 (20.71%) shoulders: in females it was absent in 13 (16.25%) shoulders, 6 (7.5%) right side and 7 (8.75%) left side, whereas in males it was absent in 16 (26.66%) shoulders, 9 (15%) on the right side and 7 (11.66%) left. It was less common in males, especially in right side shoulders.

Table 4.17.4: Thickness of the inferior glenohumeral ligament posterior band (IGHL-P) in both genders; SD: standard deviation.

IGHL-P	Both genders overall	Females	Rt side females	Lt side female	Males	Rt side males	Lt side male
Mean thickness (mm)	3.45	3.27	3.17	3.38	3.72	3.78	3.66
Range (mm)	1.3 5.84	1.43 4.77	1.84 4.48	1.43 4.77	1.3 5.84	2.36 5.22	1.3 5.84
SD (mm)	0.83	0.77	0.71	0.82	1.3	2.36	1.3



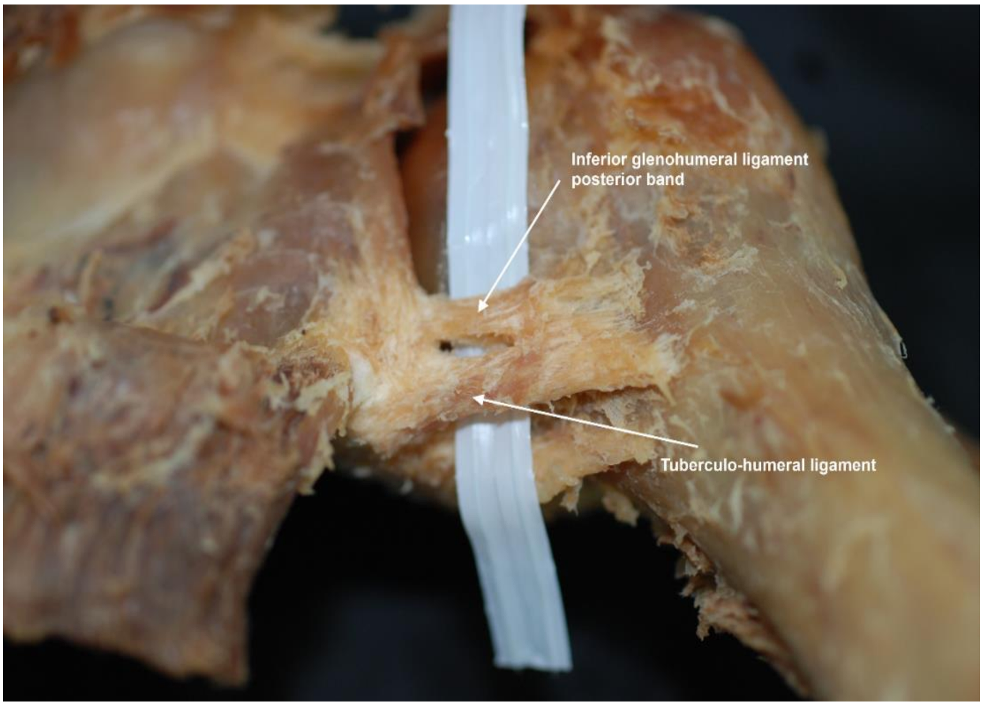


Figure 4.17.3: Right shoulder inferior view showing the inferior glenohumeral ligament posterior band (IGHLP) and the tuberculo-humeral ligament.

4.18. Bare spot

The bare spot is defined as thinning of the articular surface of the glenoid (Figure 4.18.1). It was observed in 80.71% (n=113) of shoulders, being more common in males than females. In males it was slightly more common on the left side, whereas in females it was more common on the right side (Table 4.18.1). The overall mean length and diameter in both genders were 7.16 mm and 6.19 mm (Table 4.18.2). Based on gender and side, the length and width of the bare spot were variable, being longer and wider in males: only the length and the width between males and females were statistically significant (P=0.002 and P=0.018 respectively). In females, the left side glenoid was longer but less wide compared to the right side glenoid, whereas in males, the right side glenoid was longer and wider compared to the left side: the differences were not statistically significant (Tables 4.18.3 and 4.18.4).

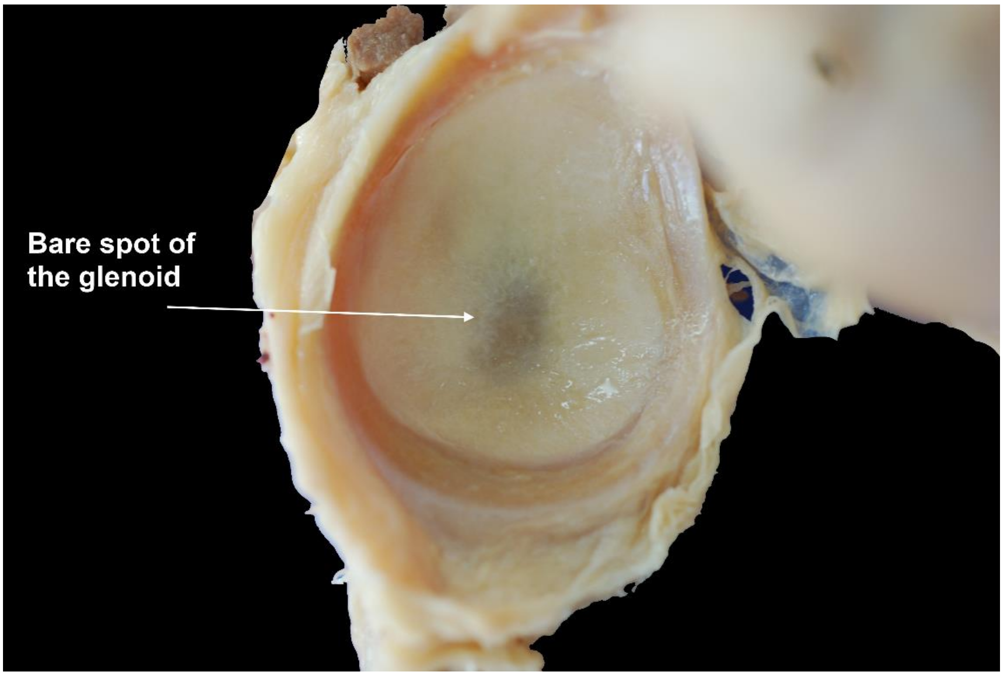


Figure 4.18.1: Right shoulder showing the bare spot.

Table 4.18.1: The bare spot in both genders.

Availability	In both genders	In females	Rt side females	Lt side females	In males	Rt side males	Lt side males
	80.71%	72.5%	37.5%	35%	91.66%	45%	46.66%

Table 4.18.2: Length and width of the bare sport in both genders.

Descriptive statistics	**Overall in both genders**	
	Length	Width
Mean (mm)	7.16	6.19
Range (mm)	2.27 - 12.58	3.03 - 11.47
Standard deviation (mm)	1.87	1.66

Table 4.18.3: Length and width of the bare sport in females.

Descriptive statistics	**Overall females**		**Right side**		**Left side**	
	Length	Width	Length	Width	Length	Width
Mean (mm)	6.64	5.84	6.57	6.29	6.73	5.36
Range (mm)	2.27 11.91	3.03 11.47	2.27 11.91	3.63 11.47	3.34 9.3	3.03 8.15
Standard deviation (mm)	1.73	1.77	1.95	2.1	1.49	1.19

Table 4.18.4: Length (L) and width (W) of the bare sport in males.

Descriptive statistics	**Overall males**		**Right side**		**Left side**	
	Length	Width	Length	Width	Length	Width
Mean (mm)	7.74	6.60	7.81	6.67	7.67	6.53
Range (mm)	5.27 12.58	4.12 11.08	5.27 12.58	4.12 9.78	5.4 12.02	6.04 11.08
Standard deviation (mm)	1.90	1.47	2.03	1.60	1.81	1.37

4.19. Origin of the long head of triceps

The long head of triceps was observed to have an extended attachment. In addition to its origin from the infraglenoid tubercle with some contribution from the posteroinferior and inferior aspects of the glenohumeral fibrous capsule, there was a fibrous slip to both sides of the superior part of the lateral border of the scapula (Figure 4.19.1). The mean width, medial and lateral thickness of the extension in both genders were 30.54 mm, 7.01 mm, 4.25 mm respectively (Table 4.19.1). The overall mean width, superior and inferior thickness were significantly greater in males than females (P=0.001, P=0.024, P=0.006 respectively). In both genders, the difference in the mean width, superior and inferior thickness between sides was not significant (Tables 4.19.2 – 4.19.3).

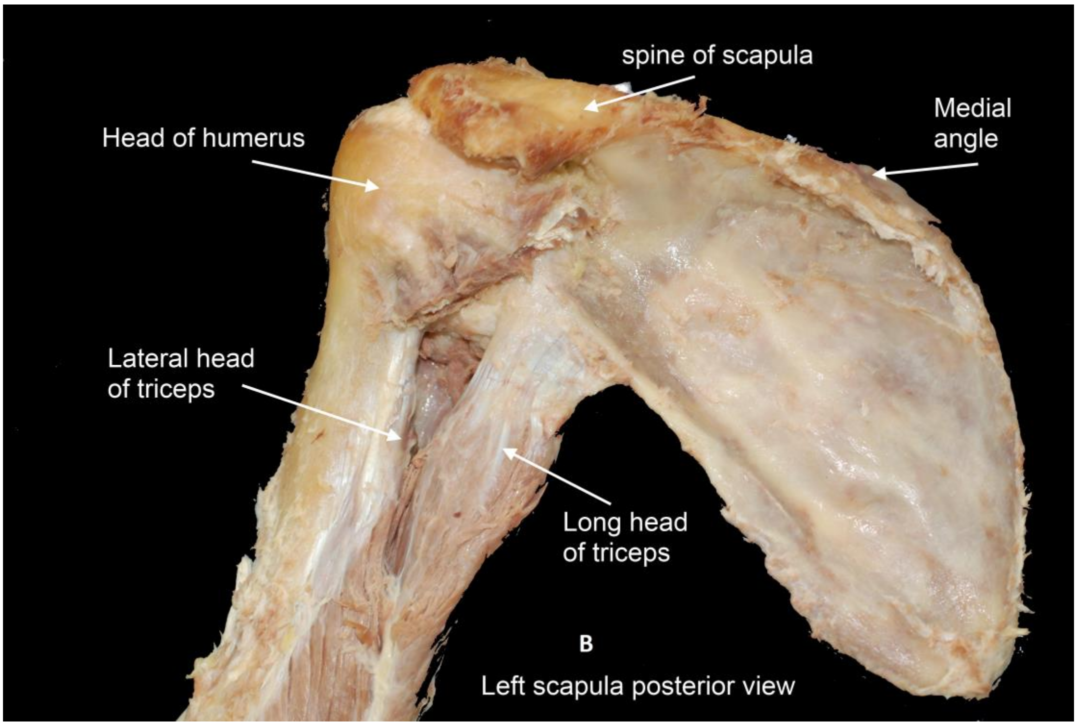


Figure 4.19.1: Left side shoulder posterior view showing origin of the long head of triceps.

Table 4.19.1: Measurements of the long head of triceps of both genders.

Descriptive statistics	Long head of triceps of both genders		
	Width (mm)	Superior thickness (mm)	Inferior thickness (mm)
Mean	30.54	7.01	4.25
Range	21.1 - 40.38	3.07 - 13.14	1.35 - 8.83
Standard deviation	3.83	1.96	1.55

Table 4.19.2: Measurements of the long head of triceps in females; W: width, S.T: superior thickness; I.F: inferior thickness.

Descriptive statistics	Long head of triceps in females (mm)			Right side (mm)			Left side (mm)		
	W	S.T	I.T	W	S.T	I.T	W	S.T	I.T
Mean	29.63	6.69	3.94	29.78	6.71	4.05	29.48	6.66	3.79
Range	21.1 37.57	3.07 12.1	1.68 7.77	21.1 37.57	3.22 11.15	1.85 7.77	13.23 22.71	3.07 12.1	1.68 7.09
Standard deviation	3.52	1.77	1.31	3.59	1.77	1.32	3.50	1.79	1.30

Table 4.19.3: Measurements of the long head of triceps in males; W: width, S.T: superior thickness; I.F: inferior thickness.

Descriptive statistics	Long head of triceps in males (mm)			Right side (mm)			Left side (mm)		
	W	S.T	I.T	W	S.T	I.T	W	S.T	I.T
Mean	31.75	7.44	4.66	31.90	7.36	4.75	31.61	7.53	4.57
Range	22.45 40.38	3.34 13.14	1.35 8.83	22.45 40.38	3.34 13.14	1.35 8.83	25.19 36.45	4.92 11.92	2.01 7.79
Standard deviation	3.91	2.14	1.74	4.43	2.39	1.88	3.39	1.89	1.62

4.20. Glenoid fossa

Measurement of the length, width and length at maximum width (Figure 3.30) of the glenoid fossa were taken with the glenoid labrum attached. The mean length, width and length at the maximum width in both genders were 38.94 mm, 30.50 mm and 17.14 mm respectively (Table 4.20.1). The overall mean length, width and length at maximum width was significantly greater in males than females ($P<0.0001$ for each). In both genders, the difference in the mean length, width and length at maximum width between sides was not significant (Tables 4.20.2 – 4.20.3).

Table 4.20.1: Measurements of the glenoid fossa parameters in both genders.

Descriptive statistics	Glenoid fossa of both genders		
	Length (mm)	Width (mm)	Length at maximum width (mm)
Mean	38.94	30.50	17.14
Range	32.7 46.07	23.03 36.82	12.99 23.66
Standard deviation	3.41	3.16	2.06

Table 4.20.2: Measurements of the glenoid fossa parameters in females; L: length; W: width; L.W: length at maximum width.

Descriptive statistics	Glenoid fossa in females (mm)			Right side (mm)			Left side (mm)		
	L	W	L.W	L	W	L.W	L	W	L.W
Mean	36.63	28.53	15.94	36.73	28.49	15.92	36.52	28.56	15.92
Range	32.7 41.01	23.03 33.81	12.99 19.24	32.7 41.01	23.03 33.15	12.99 19.24	32.91 39.99	24.03 33.81	13.26 18.87
Standard deviation	1.97	2.37	1.39	2.03	3.43	1.50	1.93	2.34	1.27

Table 4.20.3: Measurements of the glenoid fossa parameters in males; L: length; W: width; L.W: length at maximum width.

Descriptive statistics	Glenoid fossa in males (mm)			Right side (mm)			Left side (mm)		
	L	W	L.W	L	W	L.W	L	W	L.W
Mean	42.21	33.27	18.84	42.59	33.13	18.89	41.53	32.89	18.74
Range	37.62 46.07	30 36.82	16.11 23.66	37.97 46.07	30 36.82	16.69 23.66	34.48 45.05	20.37 36.67	16.11 21.6
Standard deviation	2.07	2.72	1.62	2.15	1.68	1.83	2.37	3.07	1.40

4.21. Tuberculohumeral ligament

Extending from the inferior glenoid tubercle to the posterior aspect of the surgical neck of the humerus was a ligament, which is here named the tuberculohumeral ligament (Figure 4.17.3). In the dissection of 62 shoulders (17 females, 14 males), the tuberculohumeral ligament was found in 54.83% (n=34/62) of specimens (Table 4.21.1). Based on gender and side, the thickness and length of the tuberculohumeral ligament were variable, being thicker in females and longer in males: however, only the length between males and females was significant (P=0.052). In females, it was more common on the left side, whereas in males it was more common on the right side. The overall mean length and thickness in both genders were 28.3 mm and 4.29 mm (Table 4.21.2). In females, the left side was thicker and longer, while in males the right side was thicker and longer (Tables 4.21.3 – 4.21.4). In both genders, the difference in mean length and thickness between sides was not significant.

Table 4.21.1: Incidence of the tuberculohumeral ligament in both genders.

Availability (%)	Females	Rt side females	Lt side females	Males	Rt side males	Lt side males
54.83	61.76	29.41	32.35	46.42	25	21.42

Table 4.21.2: Comparison of the tuberculohumeral ligament in both genders.

Descriptive statistics	**Tuberculohumeral ligament in both genders (mm)**	
	Thickness	Length
Mean	4.29	28.30
Range	2.68 - 6.63	20.32 - 36.49
Standard deviation	0.95	4.19

Table 4.21.3: Comparison of the tuberculohumeral ligament in females.

Descriptive statistics	**Tuberculohumeral ligament in females (mm)**		**Right side (mm)**		**Left side (mm)**	
	Thickness	Length	Thickness	Length	Thickness	Length
Mean	4.31	27.21	4.2	26.20	4.41	28.12
Range	2.68 6.36	20.32 36.49	2.77 6.2	22.46 33.85	2.68 6.63	20.32 36.49
Standard deviation	1.10	4.22	0.98	3.28	1.24	4.89

Table 4.21.4: Comparison of the tuberculohumeral ligament in males.

Descriptive statistics	**Tuberculohumeral ligament in males (mm)**		**Right side (mm)**		**Left side (mm)**	
	Thickness	Length	Thickness	Length	Thickness	Length
Mean	4.25	30.07	4.42	30.70	4.06	29.33
Range	3.24 5.33	25.33 35.39	3.33 5.33	25.33 35.39	3.24 5.01	25.89 34.5
Standard deviation	0.67	3.63	0.71	3.94	0.63	3.42

4.22. Sublabral recess

Based on the De Maeseneer et al. (2000) classification (see Figure 3.27) the following types of sublabral recess were observed. Type I, in which there is a firm attachment to the glenoid, was the most commonly seen in 73 shoulders, being more common in females than males (51 and 22 shoulders respectively). In males it was observed to be more common on the left side, whereas in females it was more common on the right side. Type II, in which a small recess can be identified between the glenoid labrum and the glenoid, was the second most common type seen in 35 shoulders, being more common in males (19 shoulders). In males it was observed to be slightly more common on the left side, whereas in females it was equally distributed. Type III, in which a deep recess is present between the glenoid labrum and the glenoid sufficient to allow the insertion of a probe, was seen in 32 shoulders and was more common in males than females. In males, it was more common on the right side, while in females it was more common on the left side (Table 4.22.1).

Table 4.22.1: Classification (%) of the sublabral recess.

Type	Both genders overall	Females	Rt side females	Lt side females	Males	Rt side males	Lt side males
Type I	52.14	63.75	33.75	30	36.66	16.66	20
Type II	25	20	10	10	31.33	15	16.66
Type III	22.86	16.25	6.25	10	31.33	18.33	13.33

Part 3: Histology

Ten shoulders (5 right, 5 left) were processed for histology.

4.23. Haematoxylin and eosin:

The glenoid labrum was observed to be a fibrocartilaginous structure being more fibrous in the free margin. The glenoid labrum was vascular with a variable distribution of the number and size of blood vessels in each region. More blood vessels were seen in the peripheral aspect of the glenoid labrum, with many coming from the fibrous capsule piercing the glenoid labrum being observed. The glenoid labrum was attached to the articular surface of the glenoid fossa centrally and the glenoid bone peripherally. Some anchors of the glenoid labrum, as attachments to the underlying glenoid bone, reached as far as the bone marrow: some of which would receive a blood supply from the bone and periosteum. In different regions, the fibrous capsule split into an internal part covering the internal aspect of the glenoid labrum and an external part which covered the external aspect of the glenoid labrum (Figures 4.23.1 – 4.23.4).

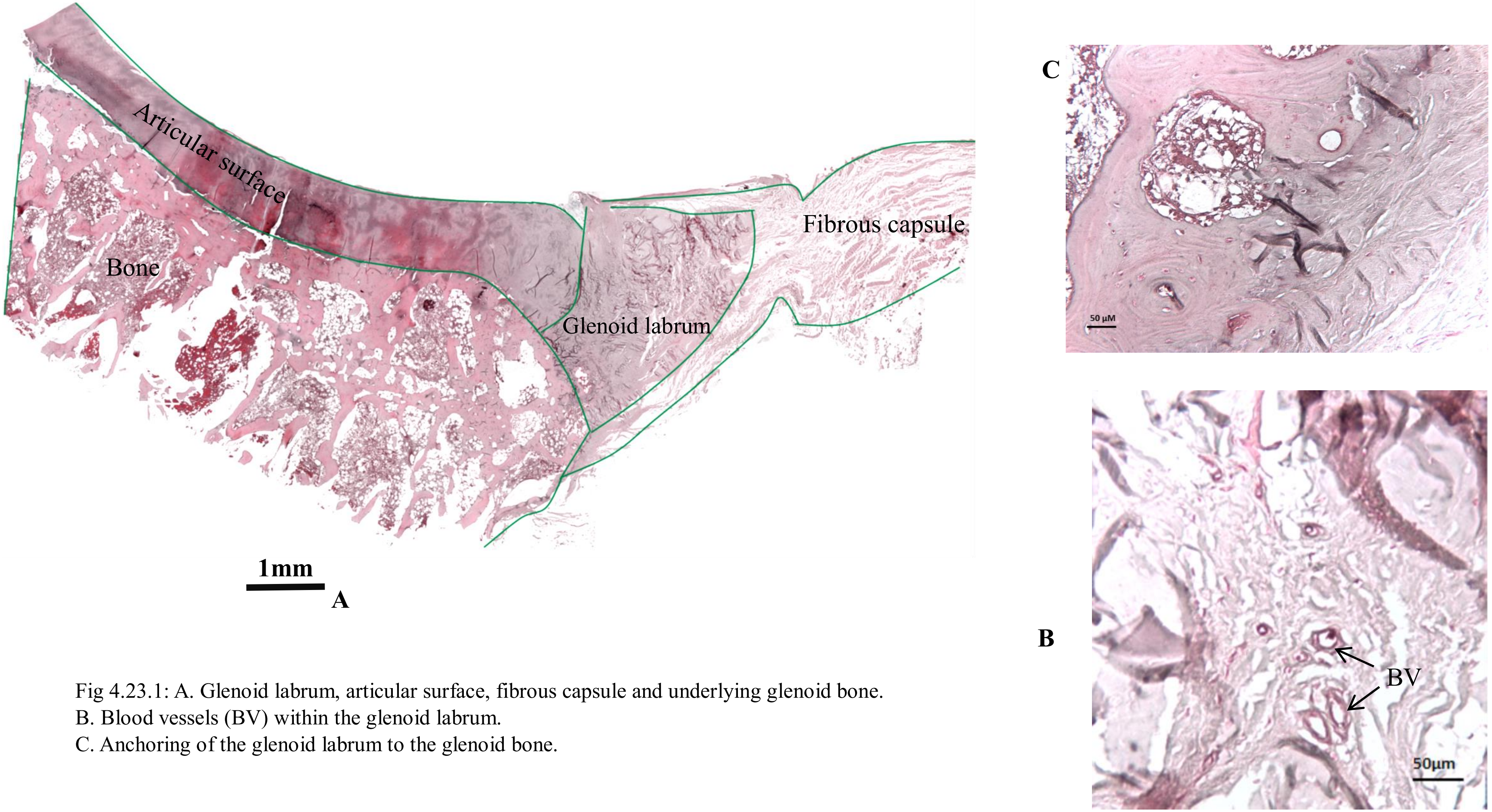


Fig 4.23.1: A. Glenoid labrum, articular surface, fibrous capsule and underlying glenoid bone.
B. Blood vessels (BV) within the glenoid labrum.
C. Anchoring of the glenoid labrum to the glenoid bone.

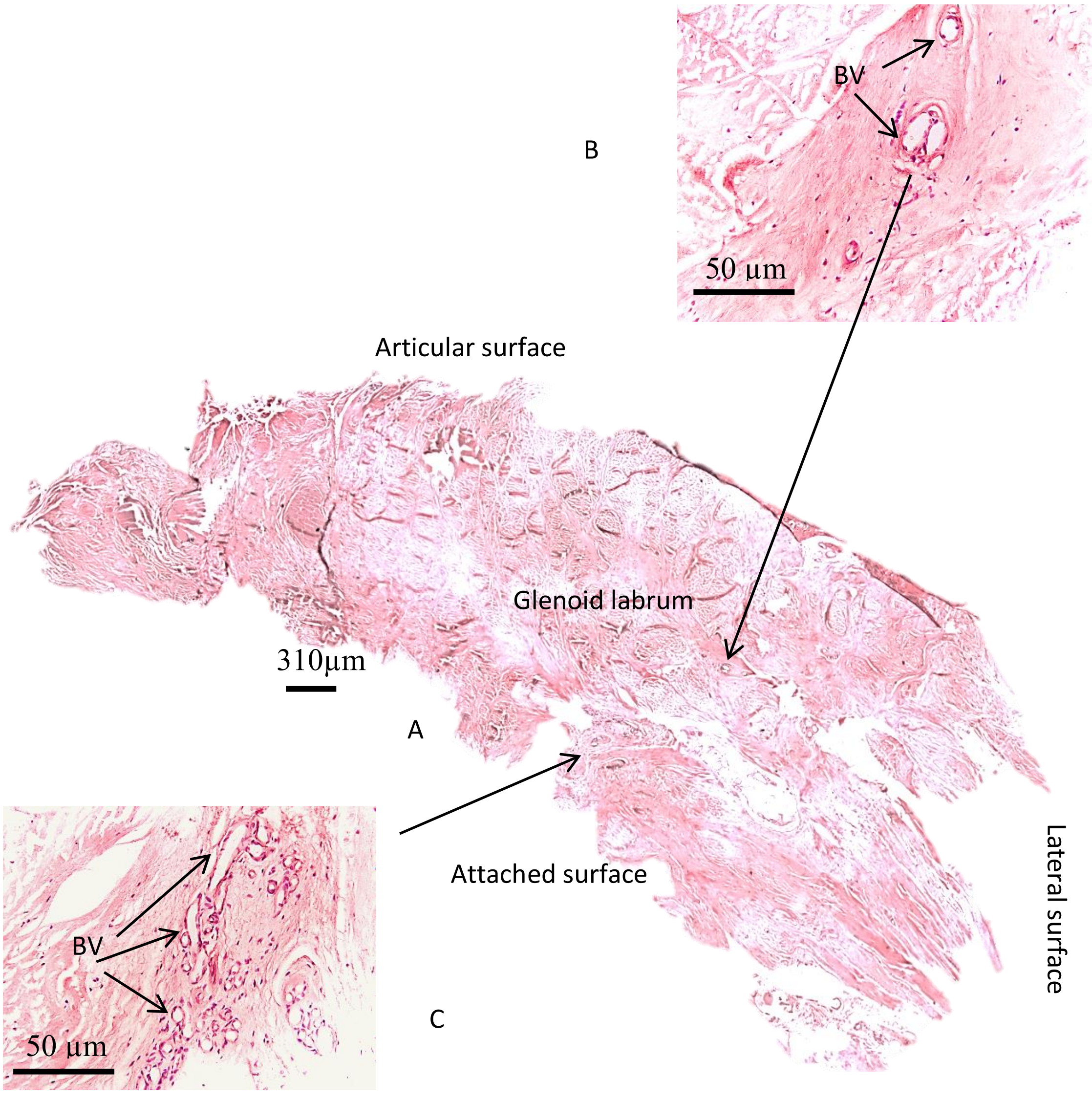
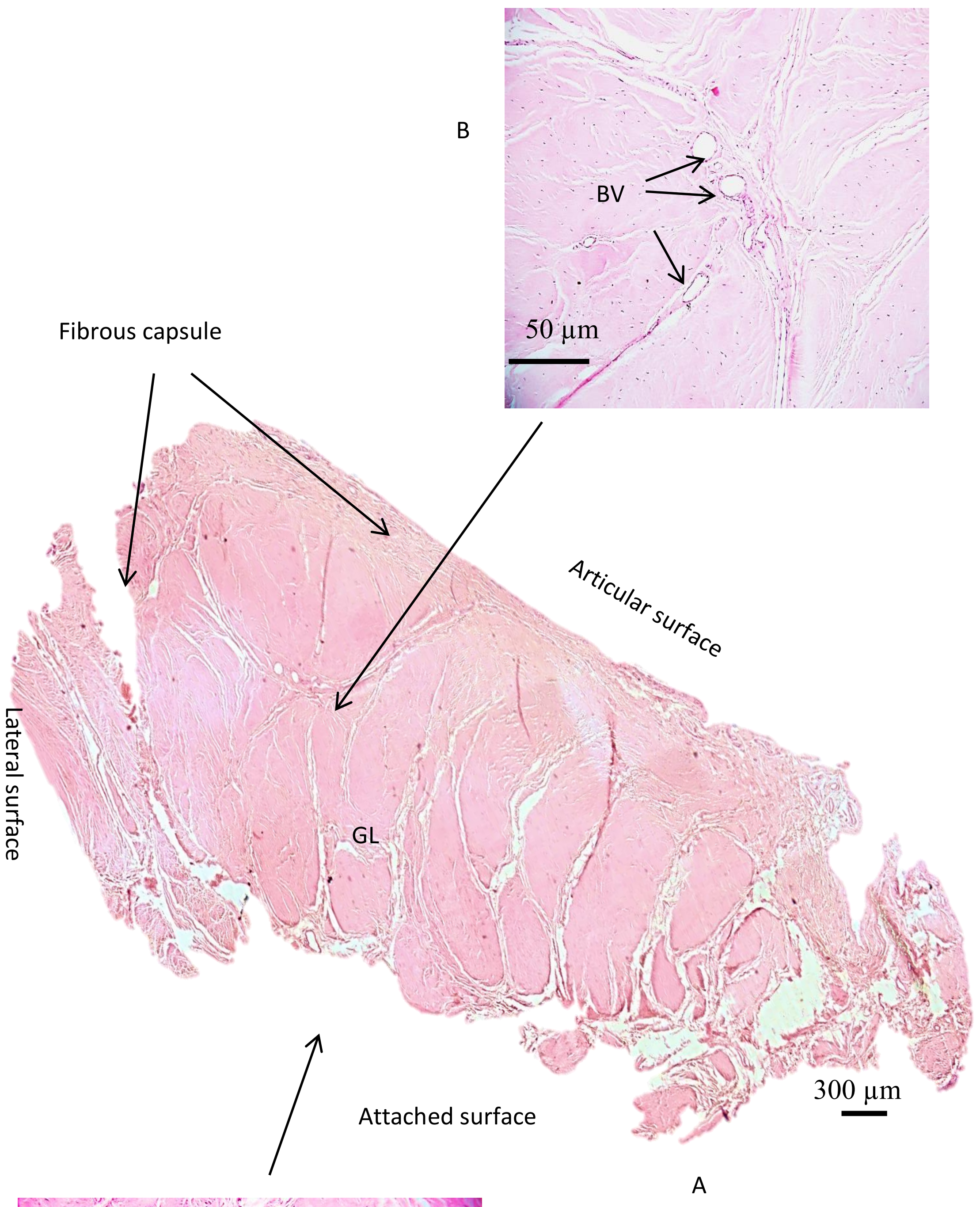


Fig 4.23.2: A. Glenoid labrum (GL) and fibrous capsule at 6 o'clock right side. B and C: Blood vessels (BV) within the glenoid labrum.



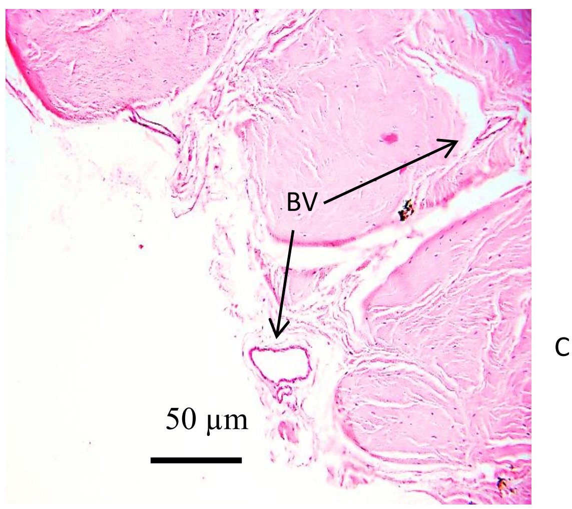


Figure 4.23.3: A. Glenoid labrum (GL) and fibrous capsule at 10 o'clock right side. B and C: Blood vessels (BV) within the glenoid labrum.

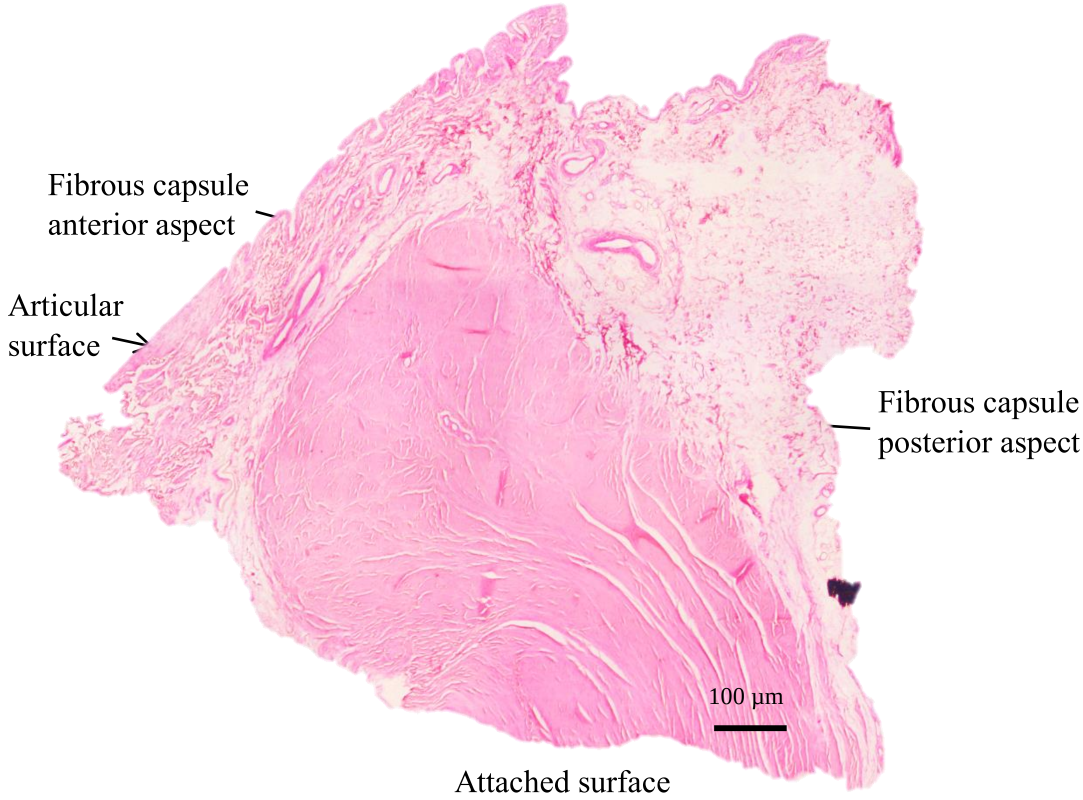


Figure 4.23.4: Show attachment of the fibrous capsule to the glenoid labrum at 11o'clock left side; GL: glenoid labrum; BV: blood vessels.

4.24. Silver nitrate:

By using silver nitrate stain, nerve fibres were observed scattered within the glenoid labrum (Figure 4.24.1).

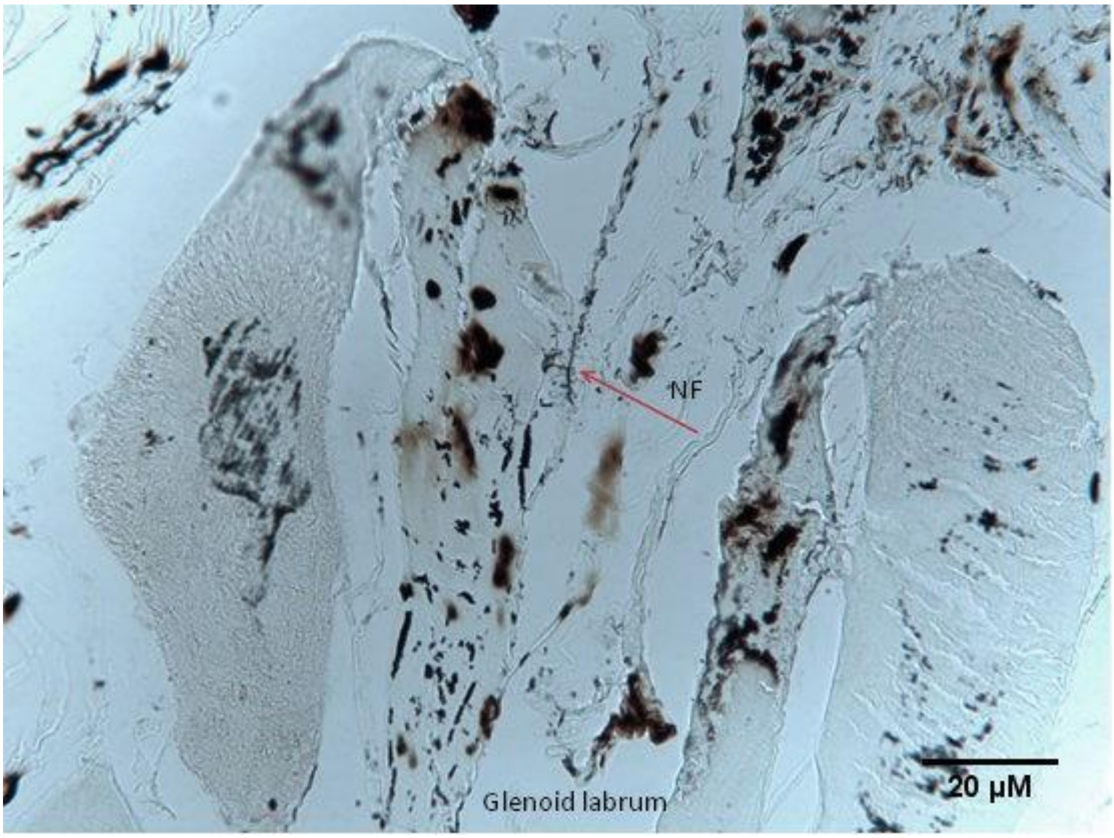


Figure 4.24.1: Glenoid labrum stained by silver nitrate showing nerve fibres (arrow).

4.25. Immunohistochemistry:

I. PGP 9.5, which is a known neuro-marker, positively stained the nerve fibres in the glenoid labrum (Figure 4.25.1). Negative control slides did not show any nerve fibre staining.

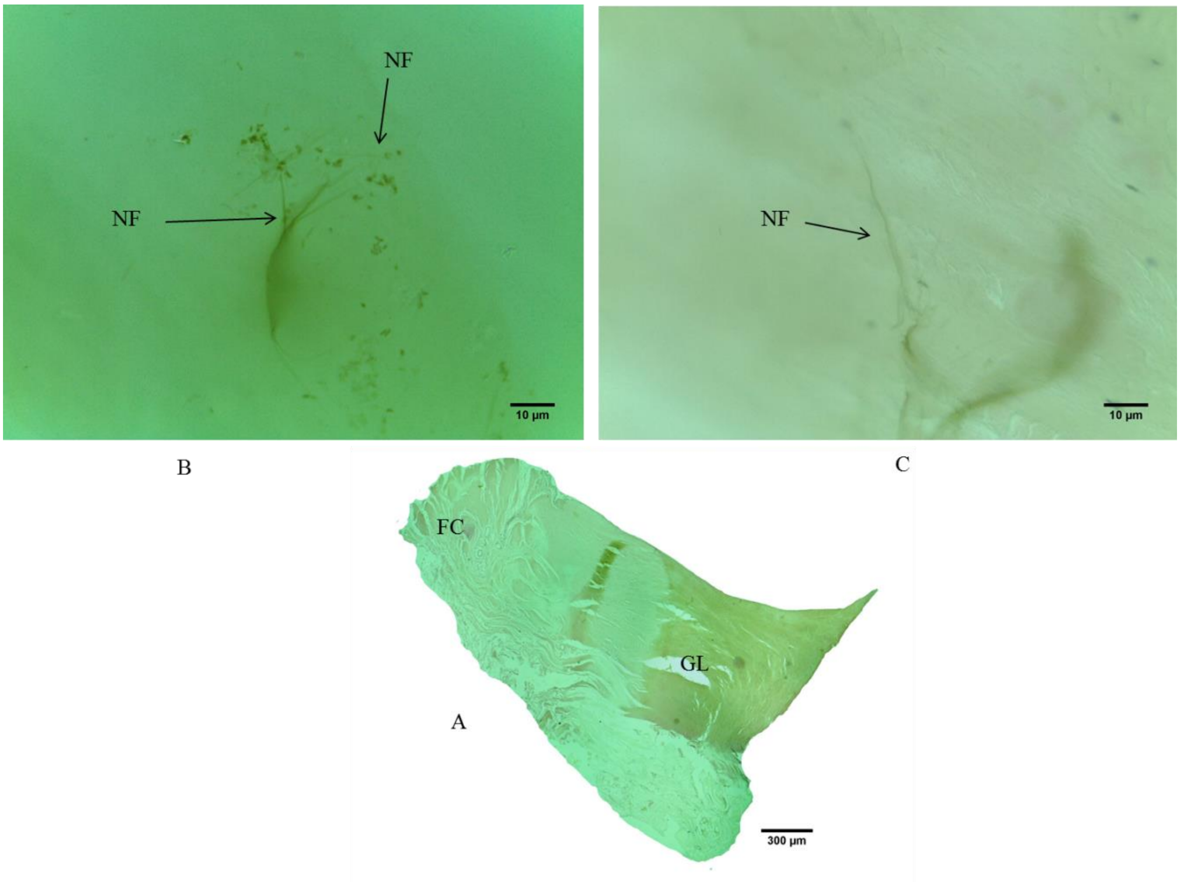
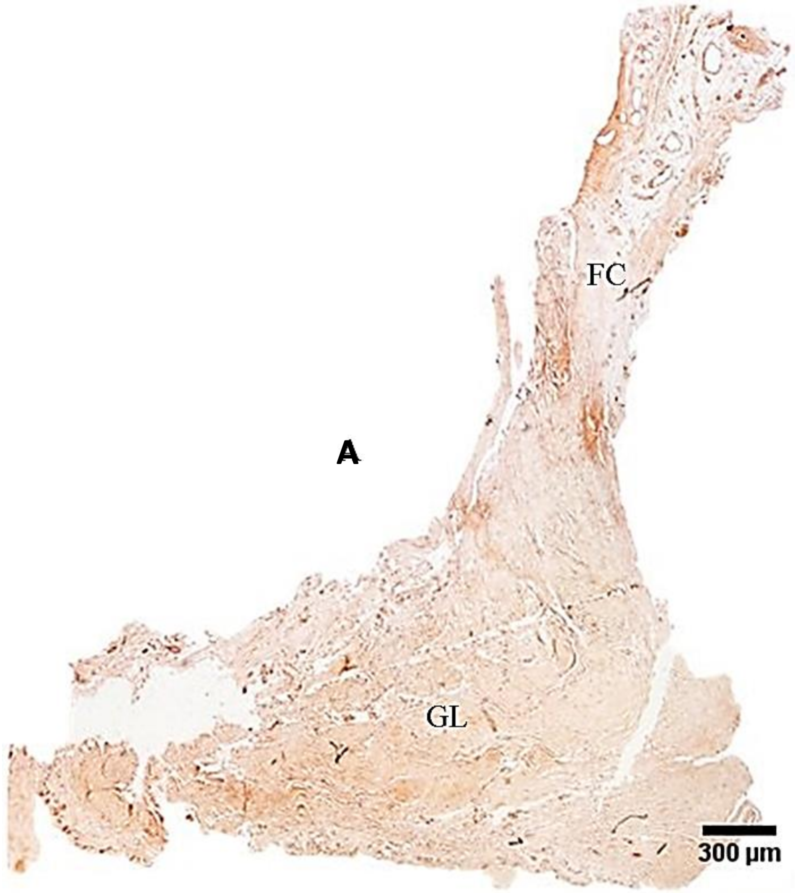
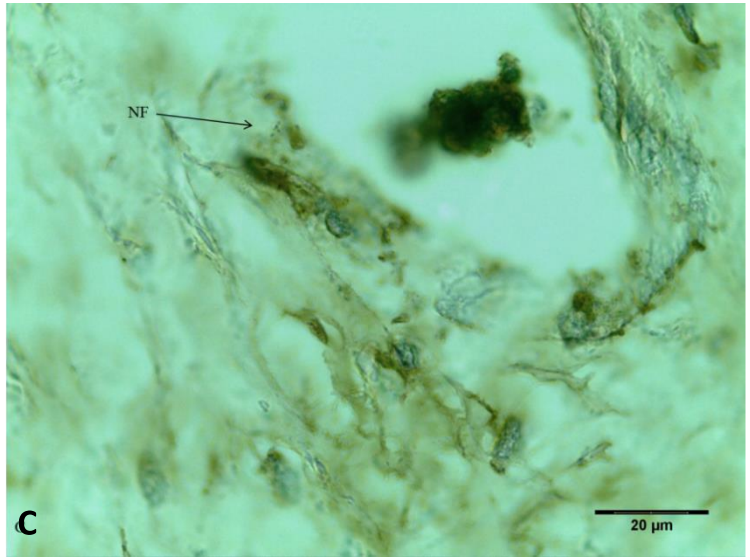


Figure 4.25.1. A: Glenoid labrum (GL) and fibrous capsule (FC); B and C: nerve fibres (NF) within the glenoid labrum.

II. CGRP, which is specific for sensory nerve fibres, stained the sensory nerve fibres within the glenoid labrum (Figure 4.25.2). Positive control blood vessels were positively stained and showed associated sensory nerve fibres (Figure 4.25.3). Negative control slides did not show any signs of nerve fibres.





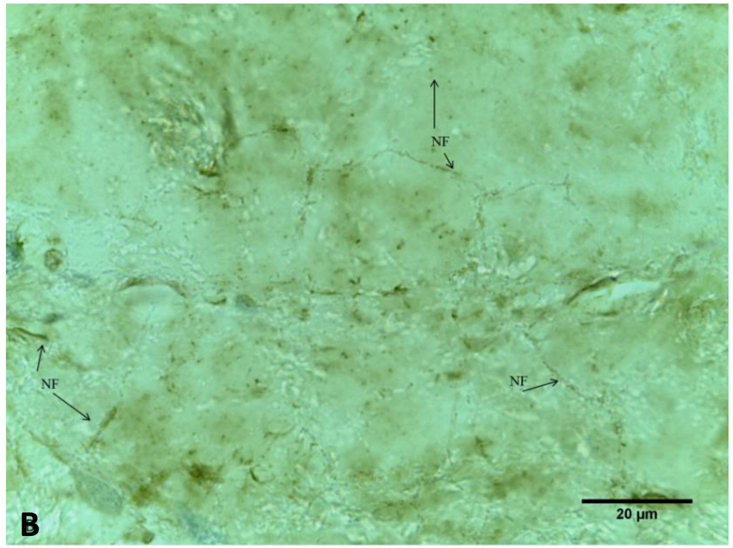


Figure 4.25.2: A. Glenoid labrum (GL) and fibrous capsule (FC).B: Nerve fibres inside the glenoid labrum. C: Blood vessel with nerve fibres in its wall.

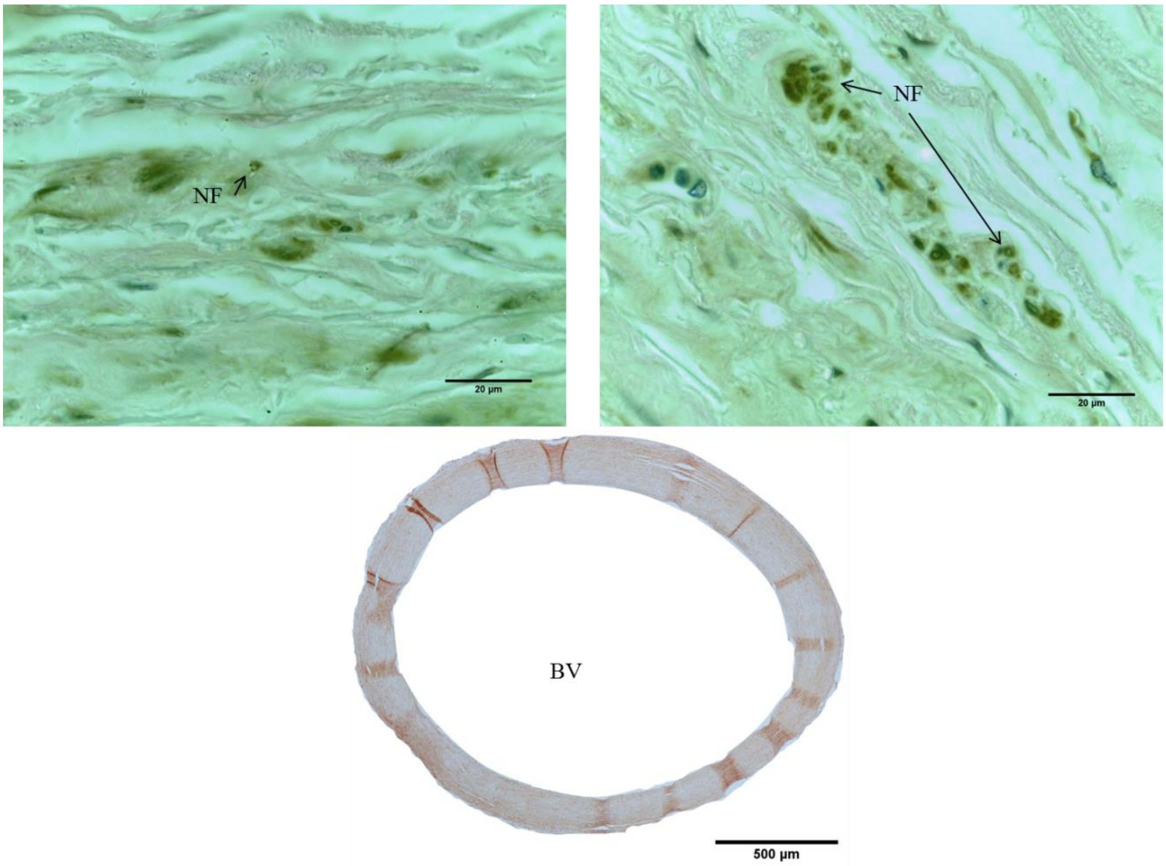


Figure 4.25.3. A: Transverse section of a blood vessel (BV) positive control. B: nerve fibres. C: nerve fibres.

Chapter 5: Discussion

5.1. Glenoid fossa, notch, surface area, volume, height, width, bare area and tubercle of Assaki.

5.1.1. Glenoid fossa:

Most texts describe the shape of the glenoid cavity as either being rounded, oval, comma-shaped or pear-shaped (Rogers, 1992; Snell, 1995; Drake et al., 2005; Palastanga et al., 2006; Moore et al., 2011), with Checroun et al. (2002) observing that 71% were pear-shaped (n=293) and 29% (n=119) elliptical. The underlying reasons for different shaped glenoid fossae are unknown. Prescher and Klumpen (1997) have suggested that the existence of a glenoid notch could result in a pear-shaped fossa after observing that a notch present in the anterior margin of the glenoid fossa in 55% (n=129) of scapulae was associated with a pear-shaped fossa. In 45% (n=107) of their sample there was no notch, as a consequence the fossa was oval. Merrill et al. (2009), however concluded that as a result of a significant difference in glenoid height and width between males and females, the fossa in males is rounded and in females is oval. Iannotti et al. (1992) state that as the transverse diameter of the lower glenoid is greater than that of the upper glenoid, the glenoid fossa has become pear-shaped. Regarding the inferior glenoid fossa, Aigner et al. (2004) observed that in 50% (n=10) of cases the inferior glenoid was circular in shape, whereas in the remainder it was circular for the inner margin of the glenoid labrum and oval for the glenoid fossa. De Wilde et al. (2004) concluded that the inferior quadrants of the glenoid fossa were circular with an average radius 14.7 mm to the peripheral articular rim. According to Huysmans et al. (2006) the inferior glenoid is circular with a diameter of 24.7 ± 2.1 mm to the glenoid cartilage rim and 30.5 ± 2.6 mm to the glenoid bone rim. However, Jeske et al. (2009) reported that the inferior glenoid was circular in all shoulders studied, adding that there was no significant difference in shape between sexes, but with males being on average 3.6 mm larger in diameter than females. The current study found that the shape of the glenoid fossa was oval in 30% (n=42) and pear-shaped in 70% (n=98). Oval-shaped fossae were more common in females (42.5%, n=34) than males (13.3%, n=8), whereas pear-shaped fossae were more common in males (86.66%, n=52) than females (57.5%, n=46). This study suggests that comma and pear-shaped glenoid fossa are more or less the same, with the first having a more severe of glenoid notch: rounded glenoid fossae were not observed.

5.1.2. Glenoid notch:

The reasons for the existence of a glenoid notch have not been explored, but a number of assumptions have been considered. Prescher and Klumpen (1997) have suggested that the tendon of subscapularis, as it passed anterior to the glenoid cavity, could be the cause of atrophic pressure on the bone leading to the formation of a glenoid notch. Merrill et al. (2009) observed a glenoid notch in 80.4% (n=148) of female and 57.6% (n=184) of male scapulae. They also put forward a classification system based on the type of the anterior glenoid notch present: in type I the glenoid notch is curved, being the most common type in both genders; in type II the glenoid notch is notched, and in type III it is scalloped. The current study believes that a glenoid notch is present in all scapulae, but with different degrees of severity. Therefore the following classification of three types of proposed: mild (I), moderate (II) and severe (III). Type III was most commonly observed (37.86%, n=53), followed by type I (34.28%, n=48) and then type II (27.86%, n=39).

5.1.3. Glenoid surface area, volume, height and width:

A number of studies have reported the surface area of the glenoid fossa and its articular surface. With regards to the articular surface of the glenoid fossa, Aigner et al. (2004) reported a value of 6.03 cm^2 with a mean circumference of 9.12 cm^2: Soslowsky et al. (1992) stated that in males and females it was 5.79 cm^2 and 4.68 cm^2 respectively. Kwon et al. (2005) reported that the mean surface area of the whole glenoid was 8.7 cm^2, while Jeske et al. (2009) reported the mean surface area of the inferior glenoid as 3.2 cm^2 with an appreciable difference between the right and left sides in the same individual. Referring to the volume and morphology of the glenoid vault, Bicknell et al. (2007) reported that the shape was rectangular in coronal section and triangular in transverse section, while Codsi et al. (2008) state that it is triangular in all cases: on this basis they suggested 5 sizes of implant that would fit any scapula. Kwon et al. (2005) report that the volume varied between 7.1 cm^3 and 21.6 cm^3 depending on the size of the scapula, adding that there is a significant consistent difference between the glenoid surface area and the glenoid vault. Based on these findings, the current study assumes that as the glenoid surface area and the shape of the glenoid vault could be important in glenohumeral joint prosthesis. Little information has been found; therefore, further research should be encouraged. Furthermore, the current study did not focus either on the surface areas of the articular surface and glenoid fossa or the volume and morphology of the glenoid vault because they were beyond the boundaries of the main goal of the study. The reasons why they are considered here and in chapter 2 earlier are: firstly, as the glenoid provides attachment for part of the glenoid labrum variations of the glenoid should be considered; secondly, future research should be conducted to find relationships between them and the mode of attachment or shape of the glenoid labrum.

The height of the glenoid fossa is variable in the literature. The current observation regarding glenoid height (length) in males is similar, while in females it is distinctly different (Mallon et al., 1992; Churchill et al., 2001; Chercoun et al., 2002; Merrill et al., 2009). This study also agrees that it is greater in males than females (Mallon et al., 1992; Churchill et al., 2001; Merrill et al., 2009). The mean height of the glenoid fossa in the current study, including the glenoid labrum attachment, in males and females was 42.21 mm and 36.63 mm respectively. The glenoid labrum therefore provides an increase in the height of the glenoid fossa: in another words it increases the surface area of the articular surface. Furthermore, this study agrees that there is a significant difference in glenoid height between males and females, which could suggest that the thickness of the glenoid labrum is proportionate to the height of the glenoid fossa thus accounting for the difference between males and females remaining significant with or without the glenoid labrum.

It could be argued that the height of the glenoid could be affected by degenerative diseases; however Bicknell et al. (2007) reported that the mean glenoid height showed no difference with respect to osteoarthritis or gender. One criticism that could be raised concerns the potential difference in measurement of glenoid height between cadaveric and living patients; however Iannotti et al. (1992) found no difference between living patients and cadavers.

With regards to glenoid width, Mellon et al. (1992), Churchill et al. (2001) and Merrill et al. (2009) all reported similar mean values in males and females, being 28.3mm and 23.6mm, 27.8mm and 23.6mm and 28.56mm and 23.67 mm respectively, being significantly wider in males (Mallon et al., 1992; Churchill et al., 2001; Checroun et al., 2002; Merrill et al., 2009). According to Iannotti et al. (1992) the mean glenoid fossa width of the lower half is 29 mm (range 21 mm – 35 mm): the width of the inferior half is larger than the superior because of the pear-shaped glenoid. The current study found that the mean width of the glenoid fossa, including the glenoid labrum, in males and females was 33.27 mm and 28.53 mm respectively, being significantly wider in males. Compared to the previous studies, it is clear that the glenoid labrum also increases the surface area of the articular surface transversely. The mean length at the maximum width in males and females were 18.84 mm and 15.94 mm respectively, being significantly different between genders. While the mean length at the maximum width in males and females is smaller than half the mean length of the whole glenoid emphasizes the fact that the glenoid fossa is pear-shaped and not rounded.

5.1.4. Bare area of the glenoid cavity and Tubercle of Assaki:

There is some controversy in the definition of the bare area and Tubercle of Assaki. Kim (2009) defined the bare area of the glenoid as a thinning of the central area of the hyaline cartilage of the glenoid cavity, whereas others describe it as a focal centrally located cartilaginous defect of the glenoid cavity present as a normal variation in adults (Ly et al., 2004, cited in Kim et al., 2010b). With regards to Assaki's Tubercle, it is defined as a thinning of the middle of the articular cartilage and thickening of the subchondral bone (Al–Mulhim 2013), which is located in the centre of the inferior glenoid cavity (Burkhart et al., 2002, cited in De Wilde et al., 2004). However, according to Warner et al. (1998, cited in De Wilde et al., 2004) the Tubercle of Assaki is defined as the thickest region of subchondral bone of the glenoid fossa due to constraining the humeral head against the articular surface of the glenoid cavity. Others have reported the Tubercle of Assaki as the bare area of the glenoid fossa (Paturet, 1951, cited in De Wilde et al., 2004). The current study partly supports Kim (2009) and Warner et al. (1998, cited in De Wilde et al., 2004), in which the bare area is a thinning of the hyaline cartilage and the Tubercle of Assaki is the thickest region of subchondral bone of the glenoid fossa. In contrast, the current study disagrees with Kim (2009), Ly et al. (2004, cited in Kim et al., 2010b), Al–Mulhim (2013) and Burkhart et al. (2002, cited in De Wilde et al., 2004) who all reported that an eccentric bare spot and Tubercle of Assaki have been observed.

The causes of the Tubercle of Assaki and bare spot are unknown; however, Warner et al. (1998, cited in De Wilde et al., 2004) believe that Assaki's Tubercle is due to constraining the humeral head against the articular surface of the glenoid cavity. The current study tends to support this concept for two reasons: firstly, the proportion of bare spots observed was 88% in an adult anatomic study (Resnick et al., 2007 cited in Kim, 2009); and secondly according to Kim et al. (2010b) the bare spot was not observed in children aged 0 – 10 years and was only seen in 12 participants between 11 and 20 years. Supporting this, Fealy et al. (2000) state, after their evaluation of 51 foetal shoulders ranging in age from 9 to 40 weeks that the bare spot of the glenoid cavity was not present. In contrast, according to Schulz et al. (2002) and Mochizuki et al. (2005) the mechanical stress was found to affect the peripheral regions rather than the central region and that the maximum density localization shows that long-term stress distribution is in the periphery.

According to Aigner et al. (2004) the bare spot was constant, variable in shape and mostly in an eccentric position within the inferior glenoid cavity. This constant appearance was assumed to be the result of the distribution of the hyaline cartilage in the glenoid cavity; therefore it cannot be taken as a marker for operative measurement. De Wilde et al. (2004) support these finding by reporting that the Tubercle of Assaki was round to oval in shape with an average diameter of 6 mm: in nine shoulders the centre of the inferior glenoid was in the anterosuperior quadrant of the surface area of Assaki's Tubercle. In contrast, Huysmans et al. (2006) found the bare spot in 87.5%

(n=35) of specimens, all of which were located in the centre of the inferior glenoid. This suggests that the bare spot is the centre of both the articular surface of the inferior glenoid and the bony inferior glenoid except for a small difference to the inferior bony rim (P = 0.02). The current study observed that a bare spot was found in 80.71% (n=113) of shoulders examined, being more common in males than females. The overall mean length and diameter in both genders were 7.16 mm and 6.19 mm, giving it a rounded to oval shape; however the length and width were significantly different (P=0.002 and P=0.018 respectively) between males and females, being greater in males.

5.2. Fibrous capsule and synovial membrane

5.2.1. Fibrous capsule:

The fibrous capsule is defined as a cylindrical sleeve of loose fibrous tissue surrounding the glenohumeral joint. A difference in the medial and lateral attachments of the fibrous capsule has been reported in literature. On the humeral side it is attached to the anterior, superior and posterior aspects of the anatomical neck of the humerus as well as the articular margins of the head just proximal to the greater and lesser tubercles, while it extends 1 cm inferiorly to attach to the humeral shaft creating a redundant fold (Robinson 1922, Palastanga et al., 2006; Smith et al., 1983; Drake et al., 2005). Robinson (1922) and Palastanga et al. (2006) suggest that the main function of the redundant fold is to allow a wide range of movement; however Williams (1995) and Monkhouse (2001) found that it becomes taut in abduction and could prevent hyperabduction.

On the scapular side, the fibrous capsule is said to attach to the glenoid neck only (Robinson, 1922; Williams, 1995). Moore et al. (2010) added superiorly some parts of the fibrous capsule extend its attachment to the base of the coracoid process. Based on these findings the fibrous capsule does not attach to the glenoid labrum.

In contrast, Uhthoff and Piscopo (1985) reported that all the posterior aspect of the fibrous capsule attached to the glenoid labrum only. Palastanga et al. (2006) support Uhthoff and Piscopo (1985) stating that not only does the posterior fibrous capsule attach directly to the glenoid labrum but also the inferior part. Others have reported that the fibrous capsule is attached to the lateral margin of the glenoid labrum as well as the glenoid bone (Smith et al., 1983; Pfahler et al., 2003).

In 1962 Mosely and Overgaard noted that the attachment of the fibrous capsule to the scapula was variable with some parts of the glenoid labrum included in the attachment, therefore they put forward a classification of three types: type I attaches to the glenoid labrum; type II at junction between the glenoid labrum and glenoid rim and type III attaches more medially. Park et al. (2000) followed Mosely and Overgaard's classification and reported that the whole part of the anterior and posterior aspects of the fibrous capsule attached only to the glenoid labrum in 63% (n=68) and 60% (n=65) of specimens respectively, the whole part of the anterior and the posterior aspects of the fibrous capsule were attached only to the glenoid bone and not the glenoid labrum in 17% (n=18) and 9% (n=10) respectively: the rest were at the junction.

The anterior and inferior aspects of the fibrous capsule attach to the ridge of the glenoid rim just medial to the glenoid labrum creating a recess between the external surfaces of the glenoid labrum internally and the internal surface of the fibrous capsule externally (Park et al., 2000). At one time the type of attachment was thought to have a significant correlation to glenoid pathology after it was observed in arthroscopy following recurrent anterior glenohumeral dislocation; however Uhthoff and Piscopo (1985) observed, after dissection of foetal glenohumeral joints, that 77% (n=40) of the anterior aspect of the fibrous capsule is attached to the glenoid labrum and 23% (n=12) attached directly to the glenoid neck allowing the recess to exist: the exact function of this recess remains to be determined.

Most anatomical descriptions at least agree that the fibrous capsule attaches to the glenoid bone. Some authors do not include the glenoid labrum to be part of the attachment (Robinson, 1922), while others appreciated its contribution in the attachment, but the variability in its contribution still exists (Uhthoff and Piscopo, 1985; Park et al.; 2000). The present study does not agree with Park et al. (2000) in which that some aspects of the fibrous capsule attaches only to the glenoid labrum or to the glenoid bone in particular the posterosuperior, superior and anterosuperior region. The current study presents a reliable histological method in which the glenoid labrum is seen to attach to the underlying glenoid bone and articular surface with the fibrous capsule attached is the best to determine the exact attachment of the fibrous capsule. It also disagrees with Uhthoff and Piscopo (1985) because their study is based on foetuses (7 - 22 weeks of gestation) where the posterior and inferior aspects of the fibrous capsule attaches to the glenoid labrum and glenoid bone.

The current observations support those of Smith et al. (1983) and Pfahler et al. (2003), based on gross anatomy and microdissection, that some parts of the fibrous capsule at the anteroinferior, inferior and posteroinferior regions split and attach to the internal and external aspects of the glenoid labrum giving the expression of it engulfing the glenoid labrum: the part of the fibrous capsule attached to the external aspect of the glenoid labrum migrates more proximally to attach to the glenoid bone. Microscopically, using eosin and haematoxylin staining, the fibrous capsule splits into two parts: an anterior one third and a posterior two thirds. The anterior part attaches to and covers the anterior ridge and internal surface of the glenoid labrum as far as the articular surface, whereas the posterior part merges with the external surface of the glenoid labrum as far the glenoid bone, where some fibres are anchored into the glenoid bone.

The orientation of the fibres of the fibrous capsule are reported to run in spiral manner from medial to lateral with the concavity facing anteriorly (Smith et al., 1983; Peat, 1986), while others state the majority of fibrous run transversely with some passing obliquely (Palastanga et al., 2006). Based on observations that the fibres become tense in extension and lax in flexion Smith et al. (1983) assumed that the capsule has a role in limiting extension to 90^0 while allowing flexion to 180^0: its exact function is still unknown. The present study observed that after removal of infraspinatus and teres minor the posterior aspect of the fibrous capsule was observed to be the thinnest part having some redundant folds: assuming these folds are unable to be seen arthroscopically because the attachment of the rotator muscles hold the stretchable fibrous capsule. Furthermore, the inferior part of the fibrous capsule was redundant, but there was still a limitation of abduction of the glenohumeral joint, therefore limitation of extension or any other movement of the glenohumeral joint cannot be based on capsular fibre orientation, but could be based on several factors such as the complexity of glenohumeral joint (such as size, shape, version, inclination), laxity of the fibrous capsule, stretchability and size of all glenohumeral joint ligaments, the rotator cuff tendons and their associated muscles.

Is the fibrous capsule strong enough to provide stability to the glenohumeral joint? Based on the literature, some authors describe the fibrous capsule as being strong and lax (Sinnatamby, 2006; Palastanga et al., 2006), while others state that it has to be reinforced to provide effective support and maintain it taut during glenohumeral joint movement (Delorme, 1910; DePalma et al., 1949; Clark et al., 1990; Warner et al., 1992) (cited by Di Giacomo et al., 2008). This supportive reinforcement is variably provided and is solely dependent on the site of attachment: from the superior, anterior and posterior are the rotator cuff tendons whereas the inferior aspect is supported by the long head of triceps as well as fibres from subscapularis anteriorly and teres minor posteriorly (Williams, 1995; Di Giacomo et al., 2008).

Controversy about the attachment of the fibrous capsule to the rotator cuff is still found in the literature. Di Giacomo et al. (2008) state that laterally the fibrous capsule is strongly attached to the inner surface of the rotator cuff near its insertion on the humerus, and becoming loose when it is in between the rotator cuff muscles and fibrous capsule and then it becomes free of attachment between the rotator cuff and the fibrous capsule at the level of the glenoid rim. Others report that the rotator cuff tendons merge with each other and with fibres of the glenohumeral joint capsule reinforcing it making it appear as one structure (Delorme, 1910; DePalma et al., 1949; Clark et al., 1990; Warner et al., 1992) (cited by Di Giacomo et al., 2008). The current study disagrees with Delorme (1910), DePalma et al. (1949), Clark et al. (1990) and Warner et al. (1992) for two reasons: the first is based on the dissections showing separation between the rotator cuff tendons and the underlying fibrous capsule was possible, in another words can be separated; and secondly on the histological finding of Clark et al. (1990), Yamazaki (1990), Clark and Harryman (1992), Gohlke et al. (1994), Gagey et al. (1993) and Cooper et al. (1993b) who found five distinctive layers and were able to differentiate between the fibrous capsule and rotator cuff. The current study partly agrees with Di Giacomo et al. (2008) in that the fibrous capsule is attached firmly to the rotator cuff distally and loosely attached at the level of the glenoid rim.

The exact function of the fibrous capsule is unknown, but has been hypothesised to provide support to the inner synovial membrane lining, restraint, a water tight seal and an extensive insertion to the peripheral tendons (Di Giacomo et al., 2008). Tears of the superior aspect of the fibrous capsule led to increased significant instability of the glenohumeral joint, leading Ishihara et al. (2014) to suggest that it provides stability to the joint. Decreasing tension on the rotator cuff tendons could help in the repair of a rotator cuff tear (Hatakeyama et al., 2001). It has also been suggested that it prevents inferior dislocation of the glenohumeral joint (Basmajian and Bazant, 1959). Other functions of the fibrous capsule, such as providing attachment to the long head of triceps, should be appreciated.

5.2.2. Synovial membrane:

Surprisingly, there is almost no published research on the descriptive anatomy and clinical functions of the synovial membrane: classically, it lines the internal surface of the fibrous capsule of the glenohumeral joint (Smith et al., 1983), with medial or lateral extensions being unclear. Some authors stated that it is attached to the margin of the articular surfaces of the glenoid cavity medially and head of the humerus laterally (Drake et al., 2005), which means that it covers the glenoid labrum but not the humeral neck. Whereas others state that it is reflected uninterrupted interiorly at the glenoid labrum and the humeral head to the articular margins of both sides (Schafer and Thane, 1892; Moore et al., 2010) suggesting that the glenoid labrum is not covered by the synovial membrane. The current study shows that the synovial layers extend as far interiorly as the articular surface of the glenoid fossa: the humeral extension of the synovial membrane was not followed since the main goal of this study was the glenoid labrum.

Extension of the synovial membrane inferiorly is still unclear. Sinnatamby (2006) and Smith et al. (1983) are of the opinion that the synovial membrane covers the bare area of the surgical neck of the humerus, which is intracapsular, extending to cover the region of the medial side of the humeral shaft between the articular cartilage and the inferior attachment of the joint capsule: if the synovial membrane extends as far inferiorly as the attachment of the fibrous capsule this means that the epiphyseal line would be intrasynovial; however according to Palastanga et al. (2006) the epiphyseal line of the medial part of the shaft is intracapsular but extrasynovial. Furthermore, the synovial membrane is redundant in the anatomical position, being stretched when the arm is abducted (Drake et al., 2005): assuming that the synovial membrane is not redundant but that it covers the redundant fold of the fibrous capsule it acquires the shape of the redundancy.

Based on anatomical and histological descriptions of the long head of biceps brachii in the classical textbooks it passes through a closed (synovial) sac. Some authors emphasize that the synovial membrane is reflected as a double-layered cylindrical sheath to invest the long head of biceps brachii within the glenohumeral joint, with the sheath extending inferiorly as far as 2 cm into the arm (Smith et al., 1983; Palastanga et al., 2006; Moore et al., 2010).

One of the functions of the synovial membrane is the secretion of synovial fluid, which according to Sinnatamby (2006) is the reason that it surrounds the tendon of the long head of biceps brachii to permit gliding when the arm is adducted and abducted. Other functions of the synovial membrane, such as providing protection to the underlying fibrous capsule and shock absorption, are as yet unclear.

Based on location, availability, function and communication some classical anatomy textbooks state that the subtendinous bursa of subscapularis is located between the fibrous capsule posteriorly and the tendon of subscapularis anteriorly (Drake et al., 2005), however Robinson (1922) and Moore et al. (2010) state that it lies between the tendon of subscapularis anteriorly and neck of the scapula posteriorly. It is constant in position, but with a variable extension (Schafer and Thane, 1892), with its lining membrane being continuous with the synovial lining of the fibrous capsule (Robinson, 1922; Schafer and Thane, 1892). It directly communicates with the glenohumeral joint cavity via an aperture in the synovial layer of the joint capsule (Moore et al., 2010) between the superior and middle glenohumeral ligaments (Gray et al., 1946; Sinnatamby, 2006; Palastanga et al., 2006): it is therefore an extension of the glenohumeral joint cavity (Moore et al., 2010) separating the neck of the scapula and the glenohumeral joint from subscapularis (Lumley et al., 1995; Abrahams et al., 2010). Furthermore, it provides a cushion and facilitates movement of the subscapularis tendon as it passes to attach to the root of the coracoid process of the scapula (Moore et al., 2010). This study observed that the subscapularis bursa has to some extent the characteristics of a hernia: herniation of the synovial sac through the fibrous capsule which could function as a dead space. The anterior wall of the subscapularis bursa was adherent to the posterior aspect of the subscapularis tendon making it appear as one structure, with any attempt to dissect the tendon of subscapularis from the bursa resulting in rupture. The posterior wall of the bursa was very well attached to the glenoid neck. Intraarticularly a pouch of the subscapularis bursa was seen to invaginate between the superior glenohumeral ligament superiorly, the middle glenohumeral ligament inferiorly and tendon of subscapularis laterally. This study reports for the first time that part of the tendon of subscapularis was intracapsular passing superior to the middle glenohumeral ligament to attach to the humerus: further histological study is needed to determine if it is intra or extrasynovial.

A number of communications of the synovial membrane has been reported in the literature. Both Ellis (2006) and Abrahams et al. (2011) are of the view that the synovial membrane communicates with the subscapularis bursa only. However, Moore et al. (2006) and Palastanga et al. (2006) are of the opinion that the joint capsule has two openings: the first being between the lesser and greater tubercles of the humerus allowing passage of the tendon of the long head of biceps brachii, the second lying anteroinferior to the coracoid process of the scapula, between the superior and middle glenohumeral ligaments, allowing direct communication between the synovial cavity of the glenohumeral joint and the subscapular bursa beneath the tendon of subscapularis.

The current study supports Ellis (2006) and Abrahams et al. (2011) because the synovial membrane was observed to be reflected as a double-layered cylindrical sheath to invest the long head of biceps brachii therefore giving the appearance that the long head of biceps brachii passes through a closed sac.

Again, based on its location there is still some confusion about the subacromial bursa. According to Drake et al. (2005) the location of the subacromial bursa is between supraspinatus and deltoid only, while others state that it lies between the supraspinatus tendon and the joint capsule inferiorly and the acromion, coracoacromial ligament and deltoid superiorly (Lumley et al., 1995; Moore et al., 2010). Robinson (1922) and Sinnatamby (2006) support Lumley et al. (1995) and Moore et al. (2010) reporting that the superior and inferior layers of the subacromial bursa are attached to the coracoacromial ligament and supraspinatus respectively, but on the other hand they do not disagree with Drake et al. (2005) in that it projects laterally with the arm in the anatomical position to lie between supraspinatus and deltoid moving medially under the acromion during abduction.

5.3. Glenohumeral, extra glenohumeral and transverse humeral ligaments.

5.3.1. Glenohumeral ligaments:

In recent years much has been published about the glenohumeral (superior, middle and inferior) ligaments. With regard to the currently acknowledged opinion, the glenohumeral ligaments are constant thickenings of the anterior region of the glenohumeral joint capsule, which can only be seen from the interior aspect of the joint (Palastanga et al., 2006; Moore et al., 2010), as revealed in classical textbooks of anatomy. Despite this, there appears to be some controversy concerning their attachment, course and presence.

Superior glenohumeral ligament:

The proximal and distal attachments of the superior glenohumeral ligament have shown variations. It has been reported to have bone to bone attachment only or bone and glenoid labrum to bone attachments. The contribution of the glenoid labrum in the attachment has been ignored in the literature. Some authors are of the view that the superior glenohumeral ligament arises from the base of the coracoid process and the superior aspect of the glenoid labrum (Williams, 1995); while others state that it originates from the glenoid neck close to the origin of the long head of biceps tendon (Di Giacomo et al., 2008). Some describe it as a slender band originating proximally just anterior to the origin of the tendon of long head of biceps brachii superior to the opening in the front the capsule, from the superior margin of the glenoid cavity, the adjacent glenoid labrum (Robinson, 1922; Gray et al., 1946) and base of the coracoid process subjacent to the coracoacromial ligament (Williams, 1995), with some fibres arising from the supraglenoid tubercle anterior to the origin of the long head of biceps tendon, some from the long head of biceps brachii and the superior glenohumeral ligament (Di Giacomo et al., 2008). The superior glenohumeral ligament arises from the supraglenoid tubercle and inserts into the lesser tuberosity (Kolts et al., 2001).

According to Kask et al. (2010) the superior glenohumeral ligament is divided into direct and oblique fibres. The oblique fibres arise as a common origin with the middle glenohumeral ligament from the supraglenoid tubercle and insert into the semicircular humeral ligament (rotator cable), while the direct fibres originate from the superior glenoid labrum and insert into the floor of the bicipital groove and lesser tubercle. The humeral attachment of the superior glenohumeral ligament is the anterior area located between the lesser tubercle and articular margin (Williams, 1995). Moreover, it has been clearly stated that it inserts into a small depression on the humeral articular surface (Di Giacomo et al., 2008). Absence of the superior glenohumeral ligament is variable ranging from 1% to 90% (Longo et al., 1996; Park et al., 2000), whereas others report that it is present in all shoulders (Wilson et al., 2012; Delorme, 1910; Welcker, 1877; Fick, 1904 (cited in Di Giacomo et al., 2008)).

The present study does not agree with Longo et al. (1996) and Park et al. (2000) but supports Wilson et al. (2012), Delorme, (1910), Welcker, (1877) and Fick, (1904) (cited in Di Giacomo et al., 2008) in that the superior glenohumeral ligament was observed in all specimens. It was seen as a single band arising from the anterosuperior aspect of the glenoid labrum between the long head of biceps attachment and the middle glenohumeral ligament, partly agreeing with Kask et al. (2010), and ran laterally to attach to the anterior aspect of the humerus agreeing with both Palastanga et al. (2006) and Di Giacomo et al. (2008). These findings do not support Kolts et al. (2001) and Di Giacomo et al. (2008) because further extension of the origin to the glenoid neck, base of the coracoid process or supraglenoid tubercle was not seen. Furthermore, the current study adds, for the first time, the thickness of the superior glenohumeral ligament in both genders at its origin: although a difference in thicknesses was noted between genders and side these were not significant. No other variations were observed.

Middle glenohumeral ligament:

There is some disagreement concerning the attachment and indeed presence of the middle glenohumeral ligament. The contribution of the glenoid labrum in the attachment of the middle glenohumeral ligament has only been mentioned in one study (Merila et al., 2008). Williams (1995) and Palastanga et al. (2006) state that it arises from the anterior margin of the glenoid as far inferiorly as the inferior third of the rim and inserts into the anterior surface of the lesser tubercle of the humerus. Kolts et al. (2001) disagree with the proximal attachment but agrees about the distal one declaring that the middle glenohumeral ligament arises from the supraglenoid tubercle, the anterosuperior aspect of the glenoid neck and base of the coracoid process. Gray et al. (1946) were more precise in the distal attachment disagreeing with Williams (1995) and Palastanga et al. (2006) stating that the humeral attachment is the inferior aspect of the lesser tubercle of the humerus. Merila et al. (2008) observed the middle glenohumeral ligament to arise from the superior neck of the scapula and anterosuperior glenoid labrum fusing with the lateral aspect of the anterior region of the fibrous capsule. Absence of the middle glenohumeral ligament is variable ranging from 12% (n=8) to 70% (n=7) (Longo et al., 1996; Merila et al., 2008; Park et al., 2000; Dewan et al., 2012).

In the present study the middle glenohumeral ligament was found in 98.57% (n=138) of specimens, being higher than in other studies (Longo et al., 1996; Merila et al., 2008;

Park et al., 2000; Dewan et al., 2012). This could be due to the number of specimens being less than in the current study, and the method employed to identify the ligament. The middle glenohumeral ligament may run slightly inferior then laterally and as such cannot be detected unless the fibrous capsule is invaginated posteriorly and stretched laterally to enable it to be hooked onto the probe: it is therefore not easy to approach arthroscopically. The present observations support Williams (1995), Palastanga et al. (2006) and Merila et al. (2008) in that middle glenohumeral ligament arises from the anterior aspect of the glenoid labrum immediately inferior to the superior glenohumeral ligament: less frequently it arises more medially along the neck of the scapula running laterally to attach to the anterior aspect of the humerus just inferior to the superior glenohumeral ligament. Furthermore, the current study found that the middle glenohumeral ligament is the thickest of the glenohumeral ligaments. A significant difference (P=0.003) was observed between genders.

Inferior glenohumeral ligament:

Several inconsistencies have been found in the literature regarding the inferior glenohumeral ligament in terms of its attachments, number of bands and presence. The inferior glenohumeral ligament is more prominent, ambiguous, longer and stronger than the middle glenohumeral ligament: it has been reported to be absent in 6% (n=3) to 60% (n=6) of specimens (Robinson 1922; Gray et al., 1946; Palastanga et al., 2006; Longo et al., 1996; Merila et al., 2008). The current study revealed that the inferior glenohumeral ligament is prominent, but thinner than the middle and superior glenohumeral ligaments, being 4.41 mm thick.

Robinson (1922), Gray et al. (1946) and Palastanga et al. (2006) stated that proximally the inferior glenohumeral ligament originates from the anterior margin of the glenoid cavity (inferior to the glenoid notch) and the anterior border of the glenoid labrum and inserts into the anteroinferior aspect of the anatomical neck of the humerus and the inferomedial aspect of the humeral neck. However, Kolts et al. (2001) stated that it originates from the scapular neck and base of the coracoid process just inferior to the middle glenohumeral ligament and inserts into the surgical neck of the humerus. Williams (1995) reported that it arises from the anterior, middle and posterior margins of the glenoid labrum only. One study (Cooper et al., 1992) revealed that the inferior glenohumeral ligament is attached firmly into the glenoid rim as well as to the anteroinferior aspect of the glenoid labrum (at 4 o'clock). There is a disagreement concerning the site of the proximal and distal bony attachment of the middle glenohumeral ligament in the literature. However, many studies agree that the glenoid labrum shares in its origin but controversy regarding the site of attachment still exists. The current study shows that the inferior glenohumeral ligament arises from the anteroinferior glenoid labrum between 3 – 5 o'clock and runs laterally to attach to the anteroinferior aspect of the humerus.

Based on the number of bands and their attachment, few studies agree that the inferior glenohumeral ligament consists of anterior and posterior bands and an axillary pouch, as well as disagreeing about their attachment. Distinct anterior and posterior bands of the inferior glenohumeral ligament with the axillary pouch between have been observed, with the anterior band attaching to the glenoid labrum between 2 - 4 o'clock and the posterior band between 8 and 9 o'clock (Fealy et al., 2000; Ticker et al., 2006). Furthermore, Gelber et al. (2006) reported that the anterior band arose from the glenoid rim midway along the anterior border, being more prominent in external rotation; however, the posterior band was only found in 41% (n=25) shoulders. In contrast, Ruiz et al. (2012) stated that the anterior band arises from the anterosuperior glenoid labrum at 3 o'clock or above only in 33.33% (n=4) of shoulders, from the middle glenohumeral ligament in 8.33% (n=1), and from the anteroinferior glenoid labrum in 41.66% (n=5). The inferior glenohumeral ligament attaches to the humeral neck in the form of a collar in 41% (n=25), to the humerus with an inferior angulation giving rise to a V-shape axillary pouch in 36% (n=22), while in 33% (n=14) it was not well defined (Gelber et al., 2006).

Based on its attachment the current study disagrees with Ruiz et al. (2012), but agrees with Fealy et al. (2000) and Ticker et al. (2006) confirming that the inferior glenohumeral ligament anterior band was found in all specimens arising from the anteroinferior aspect of the glenoid labrum between 3 – 5 o'clock running laterally to attach to the anteroinferior aspect of the humerus. The current study found the thickness of the anterior band to be 4.41 mm, with a significant difference noted between genders.

The posterior band was present in 79.28% (n=111) of specimens, which is more than Gelber et al. (2006). It arose from the posteroinferior aspect of the glenoid labrum between 7 and 9 o'clock, running laterally to attach to the posteroinferior aspect of the humerus to form, with the anterior band, the axillary pouch, thereby agreeing with Fealy et al. (2000) and Ticker et al. (2006). Furthermore, the current study found the thickness of the posterior band to be 3.45 mm: a significant difference (p=0.004) in thickness was observed between genders. The posterior band was absent in 20.71% (n=29) of the specimens: in females it was absent in 16.25% (n=13) shoulders (7.5% (n=6) right side, 8.75% (n=7) left side), whereas in males it was absent in 26.66% (n=16) shoulders (15% (n=9) right side, 11.66% (n=7) left side).

Function of the glenohumeral ligaments

The function of the glenohumeral ligaments has been evaluated by a number of investigators. The superior glenohumeral ligament stabilizes the glenohumeral joint in adduction and external rotation; the middle glenohumeral ligament stabilizes the joint in adduction, external rotation and abduction up to 45^0; while the inferior glenohumeral ligament supports the joint in adduction and adduction in external rotation between 45^0 and 90^0 (Felli et al., 2012). Despite the glenohumeral ligaments becoming taut during movement of the joint, for example lateral rotation of the humerus makes all three glenohumeral ligaments taut whereas medial rotation relaxes them, in addition when the humerus is abducted both the inferior and middle glenohumeral ligaments become taut while the superior relaxes, nevertheless they have a variable and inconsistent role in contributing to joint stability (Palastanga et al., 2006). The current study has a limitation with respect to the function of the glenohumeral ligaments as its goal was descriptive anatomy rather than biomechanics. Further studies are also required to determine the role of the new “tuberculohumeral” ligament.

5.3.2. Extra glenohumeral ligament:

An additional glenohumeral ligament has been reported by Kolts et al. (2001) in the anterior layer of the fibrous capsule arising from the axillary pouch of the inferior glenohumeral ligament and inserting into the superolateral aspect of the tendon of subscapularis. Based on gross dissection, a spiral glenohumeral ligament from the infraglenoid tubercle and tendon of the long head of triceps brachii passing superoanterolaterally anterior to the middle and inferior glenohumeral ligaments and fusing with the tendon of subscapularis to insert together in the lesser tuberosity of the humerus was observed in all specimens examined (Merila et al., 2008). The current study observed a new ligament, the “tuberculohumeral ligament”, extending from the inferior glenoid tubercle to the posterior aspect of the surgical neck of the humerus: it was present in 54.83% (n=34/62) of specimens. It was thicker in females but longer in males: however, only the length between males and females was significantly different (P=0.052). In females, it was more common on the left side, while in males it was more common on the right. The overall mean thickness of the tuberculohumeral ligament is similar to the thickness of the glenohumeral ligament, being 4.29 mm. The difference in incidence between sides and gender remains unexplored. Its exact functions are as yet unknown, but due to its location it could give an inferior and inferoposterior support to the glenohumeral joint.

5.3.3. Transverse humeral ligament:

There are a number of anatomical variations within the rotator interval; however there are controversial views regarding the presence of the transverse humeral ligament as a true anatomical ligament bridging the intertubercular groove.

Bond et al. (2005) clearly state that the transverse humeral ligament does not exist, explaining that the presence of fibrous tissue between the humeral tubercles is due to an interdigitation of two sets of fibres: the superficial part of the subscapularis tendon, which continues to attach to the greater tubercle, and the anterior fibres of the supraspinatus tendon as well as the coracohumeral ligament. Based on anatomic, MRI and histological studies Gleason et al. (2006) observed two distinct layers of tissue, with fibres running between the humeral tubercles arising as a sling from subscapularis with a small contribution from the coracohumeral ligament and supraspinatus tendon: no distinct ligamentous structure having the description of the transverse humeral ligament was observed. MacDonald et al. (2007) support this view stating that what was identified in all shoulders studied was a fibrous expansion from the posterior lamina of the pectoralis major tendon covering the tendon of the long head of biceps brachii. In

86% (n=73) of specimens the fibres from the tendon of subscapularis passed over the tendon of the long head of biceps brachii, inserting into the greater tubercle, where as in 33% (n=28) of dissections, it was observed to ran below the biceps tendon to attach either to the bicipital sulcus or the greater tubercle (MacDonald et al., 2007). Macroscopic and microscopic meta-analysis has concluded that there is no transverse humeral ligament (Tarta-Arsene et al., 2011).

In contrast, Moore et al. (2010), Palastanga et al. (2006), Drake et al. (2005) and Snow et al. (2013) disagree with Bond et al. (2005), MacDonald et al. (2007) and Gleason et al. (2006) reporting that the transverse humeral ligament is a true ligament consisting of two layers, superficial and deep. The superficial layer is thin and consists of distinct bundles of fibres, while the deep layer is fibrous tissue extending between the two edges of the intertubercular groove. The proximal part of the deep layer is a continuation of the supraspinatus tendon and coracohumeral ligament, while the distal part is formed by fibres from the subscapularis tendon. Further studies of the anatomy of the rotator interval are suggested on a larger number of specimens using more targeted histology, such as immunohistochemistry, in order to identify the morphology of the ligament and types of nerve fibres which might have clinical relevance for the glenohumeral joint.

5.4. The glenoid labrum, its anatomical variations and biceps brachii

5.4.1. The glenoid labrum and its anatomical variations:

Shape and consistency:

The shape of the glenoid labrum is variably described in the literature. According to Vesalius (1543), Smith et al. (1983) and Palastanga et al. (2006) it is a ring-like structure, triangular in cross section, with a free central margin and its base attached circumferentially to the margin of the glenoid fossa. De Maeseneer et al. (2000) emphasized that in cross section the glenoid labrum is usually rounded or triangular, but the appearance of the anterior part can be triangular, undersized, blunt-tipped or crescentic. These studies describe the glenoid labrum as a whole, however differences in shape between regions were not considered. In contrast, Cooper et al. (1992) reported regional differences stating that the anterosuperior region is triangular in cross section, while the inferior region is rounded. McNeish and Callaghan (1987) observed that the normal anterior part of the glenoid labrum was cleaved, notched or redundant. According to Haynor and Shuman (1984) and Rafii et al. (1986) the posterior labrum is rounded, while the anterior is either rounded or triangular.

Other studies have reported that the shape of the glenoid labrum is not regionally consistent: however the shape in each region among studies differs. An MRI arthrogram study showed that the glenoid labrum was triangular anteriorly in 64% (n=69) and posteriorly in 47% (n=51), rounded anteriorly in 17% (n=18) and posteriorly in 33% (n=37), flat anteriorly in 2% (n=2) and posteriorly in 17% (n=18), cleaved in 11% (n=12), and notched in 3% (n=3) (Park et al., 2000). MRI-anatomic correlations demonstrated that the morphology of the glenoid labrum is triangular anteriorly and posteriorly in 50% (n=25), crescent-shaped in 14% (n=7), rounded in 14% (n=7), flat in 8% (n=4), cleaved-shaped in 2% (n=1) and absent posteriorly in 6% (n=3) (Longo et al., 1996). Only Prodromos et al. (1990) described the consistency of the glenoid labrum, being firm and rubbery. The current study has observed that the superior half of the glenoid labrum was triangular in 95.72% (n=134), flat in 2.14% (n=3) and flat to triangular in 2.14% (n=3) of specimens, whereas the shape of the inferior half was rounded in 99.29% (n=139) and flat in 0.71% (n=1) of specimens: these findings agree with Cooper et al. (1992) to some extent, but do not agree with Park et al. (2000), Longo et al. (1996), McNiesh and Callaghan (1987) or Rafii et al. (1986). The difference in findings may be due to: (1) their methods were based on MRI and double contrast CT arthrograms, while the current study used gross dissection in which accuracy is more reliable, (2) their patients suffered from glenohumeral instability in which the shape of glenoid labrum could be changed, and (3) gender and race could have a significant association with changes in the shape of the glenoid labrum. Severe osteoarthritic changes were observed associated with a flattened superior glenoid labrum: changes in the shape of the glenoid labrum can presumably be associated with aging. Cleaved, notched, redundant or an absent posterior aspect of the glenoid labrum were not seen. The consistency of the superior half of the glenoid labrum was rubbery in 97.86% (n=137) and firm in 2.14% (n=3) of specimens because it was flat rather than triangular, whereas the entire inferior half was firm. This study supports Prodromos et al. (1990) who reported regional differences in consistency of the glenoid labrum.

Size:

The glenoid labrum has been reported to increase the width of the glenoid fossa by about 4 mm (De Maeseneer et al., 2000) and its depth by 4 mm (Smith et al., 1983; Palastanga et al., 2006). According to Howell and Galinat (1989) the glenoid labrum effectively increases the depth of the glenoid socket by 9 mm superoinferiorly and 5 mm anteroposteriorly contributing to the overall circumferential depth by 50%. Tears of the anterior glenoid labrum, such as in Bankart lesions, decrease glenoid socket depth between 2.4 – 5mm anteroposteriorly and could lead to glenohumeral joint instability. Some studies have suggested that the variation of size is due to aging (Drury et al., 2010; Prodromos et al., 1990). Drury et al. (2010) applied an anterior force at different degrees of external rotation and abduction and observed that the radial thickness and tensile modulus of the glenoid labrum varied, for instance the peak strains of a thinning glenoid labrum at the axillary region increase at 60^0 external rotation, which goes some way to explain the aetiology of thinning of the glenoid labrum with age (Drury et al., 2010). Hata et al. (1992) reported no significant correlation between the size of the glenoid labrum and the underlying glenoid bone, adding that if one region of the glenoid labrum is large other regions also tend to be larger. It was also noticed that the anterior and inferior aspects of the glenoid labrum are the largest, suggesting that they could contribute to glenohumeral joint stability. The present study has determined, for the first time, the thickness and depth of the glenoid labrum at 12, 3, 6 and 9 o'clock. Based on gender and side, the thickness and depth of these four regions varied. The thickest part was at 12 o'clock (6.01mm) and thinnest at 3 o'clock (3.93mm). A significant difference in thickness at 12 o'clock and 6 o'clock between males and females was observed, being thicker in males in all regions. The deepest part of the glenoid labrum was at 12 o'clock (5.95mm) and the shallowest region was at 3 o'clock (3.63mm). There was a significant difference in depth at 12 o'clock and 6 o'clock between males and females, being deeper in males in all the regions. The glenoid labrum thickness and depth being the smallest at 3 o'clock could explain the reason for the high incidence of anterior glenohumeral dislocation. Assuming that the majority of the cadavers were right handed: based on side the difference in depth and thickness of different genders contradicts Drury et al. (2010). Taken together the depth and thickness of the superior glenoid labrum were greater than the inferior, while the posterior measures were greater than the anterior. As the glenoid is retroverted and the inclination is superior a correlation between the size of the glenoid labrum and the angles of version and inclination, in order to compensate the differences, could be linear.

Attachment:

Generally, in the current study the superior half of the glenoid labrum was not firmly attached to the underlying glenoid bone, while the inferior half was. In some cadavers a tear of the superior half of the glenoid labrum was noticed: due to the lack of a medical history the reason behind this could not be confirmed that it was either as a result of pre-death trauma or repetitive manipulation of the glenohumeral joint during dissection.

The glenoid labrum is attached firmly to the glenoid rim and hyaline cartilage in 80% (n=8) of shoulders and unattached anteriorly and superiorly in 20% (n=2) (Longo et al., 1996). The superior region of the glenoid labrum is not well attached to the subjacent glenoid bone, thus its inner edge may protrude into the joint giving a meniscal appearance similar to the knee (Palastanga et al., 2006). A meta-analysis revealed that the superior and anterosuperior parts of the glenoid labrum are loosely attached to the glenoid process, macroscopically similar to the menisci of the knee and morphologically different to the inferior attachment (Cooper et al., 1992). Prodromos et al. (1990) noted in individuals in their fifth decade at the time of death, that the glenoid labrum was thin and virtually absent. It extended to cover the peripheral margin of the articular surface, in a similar way as the menisci of the knee, in the remaining shoulders. It has been emphasized that the glenoid labrum of individuals younger than

30 is firmly attached to the glenoid rim, while the anterosuperior region was detached in 23.52% (n=4) aged 36 and over, with the extent of the detachment increasing with age; however the fibrous capsule remained attached in all shoulders. Based on these findings, detachment of the anterosuperior region of the glenoid labrum appears to be an aging process, but confusion arises after Fealy et al. (2000) reported that by week 13 of gestation both the anterior and posterior glenoid labrum merge together; after 22 weeks, surprisingly, the anterosuperior glenoid labrum was noted to be detached from the glenoid rim while biceps was attached to the superior labrum, giving rise to the question ‘is the anterosuperior glenoid labrum normally to be unattached?’. If the aging process contributes to the shape of the glenoid labrum does it contribute to its detachment: being triangular superiorly might make it easier to detach. Furthermore, does the presence of a glenoid notch, tension in the glenohumeral ligaments and the triangular shape of the glenoid labrum have a role in detachment of the anterosuperior aspect of the glenoid labrum?

The circumferential attachment of the glenoid labrum is deficient in certain areas resulting in protrusion of the synovial membrane through these gaps (Williams, 1995), with many of its fibres attaching to the glenoid margin being short running obliquely from the internal to external aspects of the glenoid ridge (Robinson, 1922). However, Vesalius (1543) stated that the glenoid labrum surrounds the glenoid fossa and does not attach to the scapula or the humeral head, but is only like ligaments which embrace the glenohumeral joint. Its lateral surface is thick becoming thinner towards the centre of the fossa. However, Sager et al. (2009) emphasized that the glenoid labrum does not encircle the whole glenoid and has a variable size, structure, shape and mode of attachment. The attachment of the glenoid labrum posteriorly to the glenoid bone is weaker compared to the inferior aspect and is believed to be due to the posterior sublabral recesses. The present study disagrees with Vesalius (1543) and Sager et al. (2009): the glenoid labrum was observed to encircle the whole glenoid and attached variably to the underlying articular surface and the glenoid bone.

Sublabral foramen:

Variation of the anterosuperior part of the glenoid labrum is the more commonly reported (Barthel et al., 2003; Rao et al., 2003; Ilahi et al., 2002; Pfahler et al., 2003) than that of the anteroinferior (Eberly et al., 2002), posterior (Nourissat et al., 2014) or posterosuperior (Dewan et al., 2012) aspects. According to Barthel et al. (2003) the superior and anterosuperior aspects of the glenoid labrum show a wide range of morphological changes; in contrast the posterior and inferior aspects are relatively consistent. Rao et al. (2003) agree with Barthel et al. (2003) reporting that three distinct variations were observed in 13.4% (n=73) of shoulders, these being (1) a sublabral foramen (3.3%, n=18), (2) a sublabral foramen associated with a cord-like middle glenohumeral ligament (8.6%, n=47) and (3) absence of the anterosuperior aspect of the glenoid labrum associated with a cord-like middle glenohumeral ligament (1.5%, n=8). What are the causes of a sublabral foramen and is it a pathological or physiological condition? The causes for the existence of the sublabral foramen have been explored with some suggestions put forward in the literature. Barthel et al. (2003) describe it as physiological variant, with Schulz et al. (2002) supporting Barthel et al. (2003) state that it is asymptomatic clinically and predominantly found in older individuals. Therefore it is suggested that its presence is an age related development, being trauma induced if present in younger individuals. Furthermore, Schulz et al. (2004) state that the presence of a sublabral foramen is not correlated with joint instability. In contrast, Rao et al. (2003) are of the opinion that a sublabral foramen is positively associated with fraying of the anterosuperior part of the glenoid labrum, an abnormal superior glenohumeral ligament, and an increase in passive internal rotation of the arm at 90° abduction at the shoulder joint. Ilahi et al. (2002) support Rao et al. (2003) stating that the incidence of SLAP lesions was significantly higher in shoulders which have sublabral foramen and a Buford complex than in other shoulders.

The incidence of a sublabral foramen is variable. According to Park et al. (2000) it occurs in 7% (n=3) of shoulders, with Smith et al. (2008) reporting a similar figure of 10% (n=1). Wilson et al. (2013) report it to be 15% (n=16) and Pfahler et al. (2003) 16% (n=5), adding that its mean length is 7mm. In contrast Bain et al. (2012) observed a sublabral foramen in 26% (n=5) of specimens. The difference in incidence is probably due to the following reasons: firstly, the methodology employed: it was noted that a lower incidence is associated with radiological assessment, such as MRI, and a high incidence with gross dissection; and secondly the nature of the sample (cadaver or patient), number of samples, age, race and gender, these being different between studies. The current study agrees with Bain et al. (2000) that the incidence of the sublabral foramen relatively high at 28.57% (n=40) being slightly more common in males than females (31.66% (n=21) vs 26.25% (n=19)). It was also more common on the right side than the left in both genders: being more common on the right side makes the assumption that it could be an age related process as the majority of the population tend to be right handed.

Buford complex:

A Buford complex has been observed in 1.5% (n=3) – 2% (n=1) of specimens (Park et al., 2000; Williams et al., 1994; Waldt et al., 2006), while in contrast Dewan et al. (2012) report the incidence as high as 9.8% (n=5). The current study supports Park et al. (2000), Williams et al. (1994) and Waldt et al. (2006) finding an incidence of Buford complex in 2% (n=1) of shoulders examined. The reason that the incidence was high in the

Dewan et al. (2012) study is probably due to the fact that their patients also had associated glenoid labrum lesions.

The reason behind the existence of the Buford complex is unknown. Does a Buford complex cause joint instability? Several studies agree that a Buford complex is associated with glenohumeral pathology. Dewan et al. (2012) state that variations of the posterosuperior glenoid labrum and rotator cuff were correlated with the type of sport played: Buford complex was noted to be present in 9.8% (n=5) of patients. The associated lesions were of the anterosuperior aspect of the glenoid labrum in 43.13% (n=22), a rotator cuff tear in 49% (n=25), a SLAP lesion type II in 25.49% (n=13) and a Bankart lesion in 21.56% (n=5) of patients. Bents and Skeete (2005) reported a significant association between a Buford complex and SLAP lesions. Buford complex was accidentally found in a 16 year old boy with a SLAP type VI (Brue et al., 2008). Later Del Rey et al. (2009) state that full stability was accomplished in a patient with Buford complex after reattachment of the middle glenohumeral ligament to the glenoid rim after abrasion with glenoid labrum reconstruction. Based on these findings a Buford complex could be a cause for glenohumeral joint instability.

Sublabral (recess) cleft:

Why is it important to know about the sublabral sulcus? Because it can be continuous with a sublabral foramen, with differentiation radiologically between a type III sublabral recess and a SLAP lesion type II considered to be very difficult (De Maeseneer et al., 2000; Harzmann et al., 2003).

The incidence of a sublabral recess is variable being dependant on methodology, age and gender. Park et al. (2000) and Sager et al. (2009) reported a sublabral recess in 33% (n=32) to 50% (n=18) of specimens. In contrast, Smith et al. (1996) and Bain et al.

(2012) found it in 73% (n=19) to 89% (n=17) of shoulders. The current study observed a sublabral recess in all shoulders examined.

The superior sublabral recess has been classified into: type I, firm attachment to the glenoid; type II, a small recess can be seen between the glenoid labrum and the glenoid; and type III, a deep recess is present between the glenoid labrum and the glenoid sufficient to allow the insertion of a probe (De Maeseneer et al., 2000). The current study followed this classification and found that type I was the most common being seen in 52.14% (n=73) of specimens and more common in females, type II and III were seen in 25% (n=35) and 22.86% (n=32) respectively being more common in males. From these findings the current study concludes that the superior glenoid labrum is more firmly attached in females than males.

The cause and processes involved in the creation of a sublabral recess remain unclear. According to Harzmann et al. (2013) the incidence of a sublabral sulcus increases with age, suggesting that a high frequency of repetitive movement of the glenohumeral joint, such as in overhead sports, together with age and the type of insertion of the long head of biceps tendon to the superior aspect of the glenoid labrum, enhance the development of a sublabral recess. Lapner et al. (2010) support this after observing that the foetal superior glenoid labrum arises directly from the superior cartilaginous anlage with an intimate attachment between the superior glenoid cartilage and superior aspect of the glenoid labrum: in other words the sublabral recess does not exist. The current study supports Harzmann et al. (2013) and Lapner et al. (2010) because the sublabral recess was seen in all cases.

Controversially, Smith et al. (1996) reported no significant association between the type of sublabral recess and age or sex, emphasizing that there is a synovial layer lining the sublabral recess with no signs of fibrosis being detected. They therefore suggest that a sublabral recess is a normal anatomic feature.

Blood supply:

Anatomy textbooks do not mention anything about the vascularity of the glenoid labrum: in addition there are few papers available.

According to Cooper et al. (1992) the glenoid labrum is supplied by branches from the suprascapular, circumflex scapular and posterior circumflex humeral arteries, as well as capsular and periosteal branches, with the superior and anterosuperior glenoid labrum being less vascular than the remainder. No blood vessels have been observed arising from the underlying bone to supply the glenoid labrum (Cooper et al., 1992). Abrassart et al. (2006) agree with Cooper et al. (1992) that the anterosuperior region has a poor blood supply arising from the suprascapular artery, but also has an area which is avascular. The anteroinferior, posteroinferior and posterosuperior regions have a richer vascular supply arising from the posterior and anterior circumflex humeral arteries, branches from teres minor and infraspinatus as well as the suprascapular artery. The authors emphasized that there is a circumferential area about 5 mm from the glenoid edge which is completely avascular which could play a role in failure of healing following glenoid fracture. In contrast Prodromos et al. (1990) state the glenoid labrum is sparsely vascularized without any particular pattern of distribution. Nevertheless, the vascularity has been suggested to decrease with increasing age. The current study partly agrees with Cooper et al. (1992) and Abrassart et al. (2006) confirming that: (1) the superior and anterosuperior regions of the glenoid labrum receive their arterial supply from the ascending glenoid artery, articular branches from the suprascapular artery, periosteal branches from the circumflex scapular artery and muscular branches from subscapularis; (2) the anteroinferior and inferior regions receive their arterial supply from periosteal branches of the circumflex scapular artery, muscular branches from triceps and subscapularis and the inferior glenoid artery which arises either from the posterior circumflex humeral, circumflex scapular or the subscapular artery; and (3) the posteroinferior and posterosuperior regions receive their arterial supply from periosteal branches from the suprascapular artery, muscular branches from teres minor and infraspinatus, occasionally an ascending branch from the circumflex scapular artery gave periosteal branches and direct branches to these regions, branches from the anterior and posterior circumflex humeral arteries pierce the capsule anterosuperiorly, anteroinferiorly, inferiorly and posteroinferiorly supplying the anatomical neck, some of which supply the fibrous capsule and the glenoid labrum.

Based on gross dissection, the anterosuperior aspect of the glenoid labrum receives its blood supply from the ascending glenoid artery, a periosteal branch of the circumflex scapular artery and supraspscapular artery: histologically this region was rich in blood vessels therefore it cannot be less vascular than other regions of the glenoid labrum. These findings do not agree Abrassart et al. (2006) and Cooper et al. (1992) due to the following: (1) Abrassart et al. used latex silicone injected into the blood vessels; the current study found that the latex was thick and did not reach some of the blood vessels if they contained clots and not to any small size blood vessels; (2) Cooper et al. used nitric acid as a decalcifier. The current study observed that nitric acid is slow acting and has an effect on the cells of the tissue: there were hardly any nuclei left to be stained by haematoxylin which could be the reason why fewer blood vessels were seen in some regions. This bias was eliminated by using a fast decalcifier, such as formic acid, or dissecting the glenoid labrum without the underlying glenoid bone; and (3) the number of samples were small in both studies compared to the current study.

Bain et al. (2012) reported an external circumferential ridge surrounding the glenoid rim and suggested that this was due to the fibrous capsule insertion: the ridge being more obvious posteriorly. The authors reported that many nutrient foramina were present on the capsular circumferential ridge which presumably supply the glenoid bone. The current study agrees with Bain et al. (2012) but disagrees with Cooper et al. (1992) in that the glenoid labrum receives some of its blood supply from the glenoid bone for many reasons: (1) based on the histological findings, as the glenoid labrum is anchored to the glenoid bone attached to the periosteal layer which is known to be rich in blood vessels in order to supply the bone, the glenoid labrum has to have its blood supply from the periosteal layer and the glenoid bone; and (2) in surgery the glenoid labrum is trimmed and the underlying bone abraded until bleeding, following which stitching or stapling is performed with complete reattachment seen after a few months.

Functions of the glenoid labrum:

The precise function of the glenoid labrum is still unknown. Several studies agree that it provides stability to the glenohumeral joint, but the methods used, as well as the observations and interpretation about how the glenoid labrum contributes to stability differ.

Howell and Galinat (1989) reported that the glenoid labrum shares in the depth of the glenoid fossa by 50% and a Bankart lesion decreases the depth to 50% in the anterior aspect of the glenoid labrum. Based on these observation they assumed that the glenoid labrum plays a role in stability. Pouliart and Gagey (2006) resected the glenoid labrum superiorly, anterosuperiorly, anteroinferiorly and inferiorly leaving the capsuloligamentous structures intact: stability was evaluated before and after resection. The humeral head shifted inferiorly by less than 10 mm in all labral resected shoulders. Vesalius (1543), Smith et al. (1983) and Williams (1995) support Pouliart and Gagey

(2006) and Howell and Galinat, (1989) adding to stability by protecting the articular surface and helping in lubrication. The current study found that the mean glenoid labrum depth at 12, 3, 6 and 9 o'clock was variable, with the deepest part being at 12 o'clock and the shallowest region at 3 o'clock. There was a difference in depth between males and females, being deeper in males in all the regions: the differences were only significant at 12 and 6 o'clock.

Lippitt and Masten (1993), Halder et al. (2001) and Fehringer et al. (2003) (cited in Smith and Funk, 2010) stated that as the glenoid labrum contributes as much as 10% to 20% to the concavity compression of the glenohumeral joint, the existence of an intact glenoid labrum is therefore important for concavity compression in joint stabilization. According Habermeyer et al. (1992) while the glenoid labrum maintains the negative intra-articular pressure inside the glenoid it also confers joint stability, but the magnitude was not been quantified.

In contrast, Kim et al. (2013) reported that the incidence of dislocation of the glenohumeral joint was less in circumferential labral tears, posterior lesions and SLAP lesion than in Bankart/ALPSA or superior labrum detachment.

Other studies have reported different functions of the glenoid labrum. Based on an observational study Fehringer et al. (2003) stated that the function of the glenoid labrum is centralizing the humeral head under modest compressive load conditions. In contrast Vesalius (1543), Smith et al. (1983) and Williams (1995) report that the labrum also readily yields to impact and compression of the humeral head against the glenoid cavity without any restriction to free movement at the glenohumeral joint. Smith et al. (2008) disagree reporting that the function of the glenoid labrum is to transfer or counteract forces resulting from compression of the joint and humeral head translation.

Others believe the glenoid labrum extends the articular surface (Vesalius, 1543; Robinson, 1922; Smith et al., 1983). Greis et al. (2002) support this adding that loss of the anteroinferior aspects of the glenoid labrum leads to a decrease in the contact surface area from 7% to 15% compared to normal shoulders, and an increase in contact pressure from 8% to 20%. The magnitude of these values might have some bias because firstly the size sample was very small, secondly the authors had removed all the soft tissue around the shoulder which could affect the reading, and thirdly their method of determining the surface area, using a flat paper cut out to replicate the dimensions of the each specimen face then scanned with a computerized digital scanner to determine their area, could be misleading because (1) the glenoid labrum has a variable shape and (2) the fibrous capsule and glenohumeral ligaments merge into the glenoid labrum which almost certainly influenced the values obtained. In comparison to measurements of the glenoid fossa without the glenoid labrum (Mallon et al., 1992; Churchill et al., 2001; Bicknell et al., 2007; Merrill et al., 2009), the current study agrees that the glenoid labrum increases the surface area of the articular surface.

5.4.2. Biceps brachii:

Attachment:

Several anatomical studies agree that the long head arises from the superior glenoid labrum and the supraglenoid tubercle at the superior aspect of the glenoid cavity by a long tendon which runs inside the fibrous capsule engulfed in a sheath of the synovial membrane (Moore et al., 2010; Gray et al., 1946; Palastanga et al., 2006; Lapner et al., 2010; Bain et al., 2012), while others state that it originates from the superior glenoid labrum and tendon of supraspinatus (Kim et al., 2009a): the contribution of the glenoid labrum in the attachment of the long head of biceps tendon has been quantified but a diversity in the incidence and site have been observed in the literature.

According to Bain et al. (2012) the long head of biceps originates from the supraglenoid tubercle with a contribution of up to one third from the superior glenoid labrum in all specimens. Pfahler et al. (2003) stated that the long head of biceps arises from the supraglenoid tubercle in 22% (n=7), from the superior glenoid labrum in 38% (n=12) and from both the supraglenoid tubercle and superior glenoid labrum in 40% (n=13). Paul et al. (2004) agree that the long head arises consistently from the supraglenoid tubercle and glenoid labrum, but the tendon is also attached to the posterior part of the glenoid labrum in 67% (n=41) and to the anterior part in 33% (n=20).The tendon of the long head of biceps brachii passes posteriorly along the superior edge of the glenoid in the majority (92%, n=45) of shoulders (Arai et al., 2012).

Chauhan et al. (2013) support Paul et al. (2004) also stating that the origin is from the anterior labral margin from its upper half in 30% (n=15), where that of the posterior labral margin is from the upper half in 60% (n=30) and the lower half in 40% (n=20) of cases. In contrast, Periyasamy et al. (2012) reported that the long head of biceps arises from the supraglenoid tubercle blending with the posterior glenoid labrum in 58% (n=29), with anterior and posterior glenoid labrum in 39% (n=19) and with the anterior labrum in 3% (n=2) with only a few fibres blending with the posterior glenoid labrum. Reis et al. (2009) disagree with Pfahler et al. (2003) and Periyasamy et al. (2012) reporting that it arises from the posterior glenoid labrum in 95% (n=19) and from the supraglenoid tubercle in 5% (n=1) of specimens. The current study supports Moore et al. (2010), Gray et al. (1946), Palastanga et al. (2006), Lapner et al. (2010) and Bain et al. (2012) adding that the attachment of the long head of biceps to the superior glenoid labrum is variable with the majority having a posterior orientation. In some cases extended fibrous bands were attached to the fibrous capsule.

Classification:

These variations in the attachment of the long head of biceps are the main reason to the existence of different classifications. According to Chauhan et al. (2013) the long head of biceps tendon persistently originates from the supraglenoid tubercle and the glenoid labrum, however the mode of attachment to the glenoid labrum is variable and can be classified into three types. In type I it arises from the supraglenoid tubercle and the posterior margin of the glenoid labrum, observed in 74% (n=37) of specimens; in type II it arises from the supraglenoid tubercle and most of the posterior glenoid with some contribution from the anterior labrum, observed in 20% (n=10) of specimens; and in type III it arises from the supraglenoid tubercle and glenoid labrum with an equal contribution of both anterior and posterior aspects, observed in 6% (n=3) of specimens. Vangsness et al. (1994) classified the attachment based on the dissection 100 fresh frozen shoulders. The tendon was found to arise from two sites, approximately 50% (n=50) for each part, the supraglenoid tubercle and the superior glenoid labrum which was classified as type I, with all fibres attaching posteriorly, observed in 22% (n=22) of specimens; in type II fibres mostly attached posteriorly with some anteriorly, seen in 33% (n=33) of specimens; in type III, there was an equal contribution anteriorly and posteriorly, seen in 37% (n=37) of specimens; and type IV had most fibres attaching anteriorly with a small part posteriorly, observed in 8% (n=8) of specimens. Several authors have subsequently used the Vangsness et al. classification in their studies with broadly similar results: the reason presumably being that it is easier to follow. The present study observed variability of the labral attachment with the majority (type I + type II=73.56%, n=103) being posteriorly oriented and splitting between anterior and posterior aspect of the glenoid labrum (type III) in 15% (n=21). Even type IV has some contribution to the posterior aspect of the glenoid labrum. These findings support

Vangsness et al. (1994) adding that Type I was more common in males than females. In males it was observed to be more common on the right side, whereas in females it was more common on the left side. Type II was the second most common type, being more common in females: in males it was observed to be more common on the left side, whereas in females it was more common on the right side. Type III was more common in males than females: in males it was more common on the left side, while in females it was more common on the right side. Type IV was more common in males and on the right side in both genders. The reasons behind the differences in the incidence between types, gender and side are as yet unexplored.

Associated pathology:

The intra-articular part of the long head of biceps tendon shows variations which can be categorized into a series of groups from simple vinculum, cord, pulley type to partial or complete adherence to the fibrous capsule or to the rotator cuff. Kanatli et al. (2011) found that 7.4% (n=50) of these variations were associated a higher prevalence of labral pathology. According to Kim et al. (2009a, e) and Zhang et al. (2014) the long head of biceps arises from the superior glenoid labrum and tendon of supraspinatus with the intra-articular course of the tendon completely adherent to the rotator cuff. Egea et al. (2010), Cheema and Singla (2010) and Hammond and Bryant (2013) all reported the long head of biceps tendon arising from the fibrous joint capsule. However, according to Gaskin et al. (2007) a bicipital glenoid labrum complex does not exist. In the present study the long head of biceps was completely degenerated in 7.14% (n=10) of shoulders and was attached to the superior aspect of the fibrous capsule instead: it was more common in females than males. In females, it was double the incidence on the right side than the left, while in males it was only observed on the left side. It was noticed that these glenohumeral joints had severe arthritic changes leading to tendon tears: it is assumed that the long head of biceps tendon re-attached to the superior aspect of the fibrous capsule by fibrosis. An understanding of these anatomical variations and age-related tear processes is essential in order to prevent misdiagnosis and to help in the evaluation and treatment of glenohumeral joint pathologies.

5. Instability and dislocations of the glenohumeral joint.

5.5.1. Instability of the glenohumeral joint:

According to Smith et al. (1983), Lumley et al. (1995), Drake et al. (2005), Palastanga et al. (2006), Sinnatamby (2006) and Abrahams et al. (2011) the glenohumeral joint is unstable due to the disproportionate nature of the articular surfaces, as well as the laxity of the joint capsule. Several factors contribute to stabilization. Firstly, the glenoid labrum deepens the glenoid fossa effectively extending its articular surface, secondly the rotator cuff muscles, and thirdly the coracoacromial arch. Beltran and Suhardja (2007) and Karahan et al. (2012) disagree stating that the glenohumeral joint is stable with its complexity allowing a great range of mobility. Stability of the joint is essentially maintained by active and passive mechanisms. The passive mechanism relies on the glenoid labrum, adhesion and cohesion of the articular surfaces, the fibrous joint capsule, the glenohumeral ligaments and the size and shape of the glenoid fossa; while the active mechanism includes the rotator cuff muscles and tendon of the long head of biceps. Thus, any pathology of the glenoid labrum, such as Bankart, Perthes or ALPSA lesions, the glenoid cavity (congenital or traumatic induced version insufficiency), the glenohumeral ligaments and fibrous capsule (laxity and deformity of the joint capsule), the humeral head (congenital or traumatic induced version insufficiency), the long head of biceps tendon (SLAP), or rotator cuff muscle tears could cause glenohumeral joint instability.

The correlation of the glenoid labrum and instability has been investigated differently, with some studies observing that instability arises when a tear to the glenoid labrum occurs but each study observed it differently. Yamamoto et al. (2009) reported that the stability ratio of the glenohumeral joint is significantly decreased after a defect of 6 mm in the width of the anterior glenoid labrum, suggesting that the anterior glenoid labrum plays a role in anterior glenohumeral stability. Gates et al. (2009) state that shoulders with superior, anterior and posterior labral tears associated with displacement of the biceps anchor have a major effect on stability. Wellmann et al. (2011) mention that significant instability of the joint was apparent inferiorly with posterior capsular lesions, posteriorly in posterior glenoid labrum lesions, and posteroinferior in combined lesions. In contrast, Youm et al. (2008) agree that a superior labral anteroposterior lesion type II increases external rotation significantly by 2.7^0 associated with a small increase in anterior (0.9 mm) and posterior (0.9 mm) joint translation, but not to the level that it affects the kinematics of passive movement of the joint.

Other authors have recognised the function of the glenoid labrum when stability of the glenohumeral joint has been re-achieved after either open surgical or arthroscopic re-attachment of the labrum was accomplished; however each study observed it differently. Black et al. (1999) state that a three site repair of the anterior glenoid labrum lesion resulted in a significant decrease in humeral translation and increased stability to the joint. Mazzocca et al. (2011), supporting Black et al. (1999), report that patients had 2+ or more anteroinferior instability and bilateral instability and all underwent arthroscopic 270^0 suture anchors of the detached glenoid labrum. The postoperative outcome was highly effective, with complete joint stability being achieved in 85% of patients. Atay et al. (2002) report that complete stability was accomplished after two staples were used to reinsert the glenoid labrum and other tissues in place and a capsulolabral tissue repair undertaken in anterior labroligamentous periosteal sleeve avulsion of the superior part of the glenoid labrum (ALPSA). Kim et al. (2008b) introduced a new technique using a single suture anchor with two non-absorbable braided sutures to repair the glenoid labrum and fibrous capsule separately. It increased the strength of the labral repair and also allowed for a reduction in fibrous capsule volume to restore stability. Extending this, Lino and Belangero (2006) introduced a triple combined procedure which included labral repair, reduction of the fibrous capsule volume and suture of the rotator cuff interval. When performed on patients with a mean follow up of 32.4 months stability was observed in all shoulders with a marked functional improvement. Based on these findings the glenoid labrum clearly plays a role in stability and it has a rich blood supply enabling it to re-attach despite the different fixation techniques.

In contrast, Mihata et al. (2008) disagree with Mazzocca et al. (2011), Black et al. (1999) and Atay et al. (2002) reporting that anterior glenohumeral joint instability is still observed after the repair of an anteroposterior labral lesion type II associated with anterior capsular laxity. Ahmad et al. (2003) partly support Mihata et al. (2008) reporting that instability of the glenohumeral joint still exists after repair of Bankart lesions in patients with labral deficiency and anteromedial capsule redundancy with an incidence of 49% (n=38), stating that performing the medial capsule imbrication technique and buttressing the glenoid, which is known as barrel stitch, achieves stability in 92% of patients. Kim et al. (2013) disagree with Yamamoto et al. (2009) stating that there is no correlation between the extent of the labral lesion and the frequency of glenohumeral dislocation. The authors found that recurrent dislocation had a significantly higher proportion of inverted pear-shaped glenoids, being 13.51% (n=15). Alberta et al. (2006) reported that 10 mm anteroinferior arthroscopic suture plication was applied and an effective significant reduction observed in anterior translation and external rotation. Bohnsack et al. (2009) declared that arthroscopic anatomic reconstruction of a Bankart lesion with suture anchors without over-constraint of the anteroinferior aspect of the fibrous capsule provides sufficient stabilization.

5.5.2. Dislocation of the glenohumeral joint:

Anterior dislocation:

Due the presence of the rotator cuff muscles Palastanga et al. (2006) and Sinnatamby (2006) assume that anterior dislocation is less frequent. Bankart (1923), Ufberg et al. (2004), Chechik et al. (2011) and Gutierrez et al. (2012) disagree stating that as the glenohumeral joint is the most mobile joint in the body with anterior dislocation accounting for the majority of glenohumeral dislocations. The current study supports Bankart (1923), Ufberg et al. (2004), Chechik et al. (2011) and Gutierrez et al. (2012) for several reasons: (1) the thinnest and shallowest part of the glenoid labrum is the anterior aspect; and (2) the attachment of the anterior glenoid labrum to the underlying glenoid bone is generally loose. These could explain the underlying causes of the high incidence of the anterior glenohumeral dislocation. However, other factors could also contribute such as the grade of the glenoid notch and degree of glenoid inclination.

The position of the humeral head in anterior glenohumeral dislocation has been described, with Palastanga et al. (2006), Gudena et al. (2011), Dlimi et al. (2012) and Ballesteros et al. (2013) stating that during dislocation the humeral head passes between the inferior glenohumeral ligament and the long head of triceps to lie inferior to the coracoid process thus creating a bulge at the clavipectoral groove: at the same time the contour of the shoulder joint disappears. In contrast, others report the humeral head to be displaced inferoanteriorly (Faiz and Moffat 2006; Moore et al., 2010). The current study believes that displacement of the humeral head inferoanterior is in more or less the same place, i.e. inferior to the coracoid process just a different description. The reason that the humeral head displaces anteroinferiorly could be due to the concavity of the anterior aspect of the glenoid neck and inclination of the glenoid fossa.

Auffarth et al. (2013) reported that recurrence after first time traumatic anterior glenohumeral dislocation is common. Wheeler et al. (1989), Milgrom et al. (2014), Bottoni et al. (2002), Te Slaa et al. (2003) and Jakobsen et al. (2007) observed that the recurrence rate of anterior glenohumeral dislocation in young athletics is up to 92%. Based on the high incidence of anteroinferior glenoid labrum lesion in first time dislocation, which can reach 66.6% (n=22) in first time dislocation and 98.1% (n=109) in recurrent dislocation (Kim et al., 2010a), the current study believes the reason of this high incidence in recurrence is linked to glenoid labrum tears.

Several factors have been reported to cause acute anterior glenohumeral dislocation: Bankart (1923), for example, reported falling on an abducted arm. Chahal et al. (2010) agree also stating that capsular laxity or muscle contraction can cause anterior dislocation. In recurrent dislocation Auffarth et al. (2013) assume that an undiagnosed glenoid bone lesion is the cause. Bankart (1923), however disagrees stating that abnormal capsular laxity and weakness of the surrounding muscles, or falling on the posterior aspect of the glenohumeral joint can lead to dislocation. In the literature dislocation is always considered to be the cause of a glenoid labrum tear and not vice versa; in other words tears of the glenoid labrum occur as a cause of dislocation, with no clear evidence that first time dislocation occurs as a consequence of a glenoid labrum tear due to another pathology.

Several lesions are associated with first time traumatic anterior glenohumeral dislocation of which the glenoid labrum is involved, but their incidence are diverse. Bankart (1923), Dlimi et al. (2012) and Auffarth et al. (2013) report that it is associated with glenoid rim fracture (41% - 86%), Hill-Sachs lesion (40%, n=8) and fracture of the greater tuberosity (15%, n=3). However, Gutierrez et al. (2012) observed that a Bankart lesion was an association in all patients. Based on the findings of the current study, as the superior half of the glenoid labrum is not firmly attached to the underlying bone, a Bankart lesion could be the most common among lesions of the glenoid labrum.

Comparing recurrent anterior dislocations and first time anterior dislocation, posterior Bankart and SLAP lesions were more frequent in recurrent anterior dislocation. Moreover, Hill-Sachs lesions of different size and Bankart lesions were seen in all patients and SLAP lesions type I and III were found in 7.40% (n=2) (Bottoni et al., 2002). A Baker lesion was also observed in 93.5% (n=71) of patients by Jakobsen et al. (2007). The current study supports Bottoni et al. (2002) because the reason for SLAP and Bankart lesions being the most common is due to the mode of attachment of the glenoid labrum.

Lesions of the fibrous capsule as a consequence of anterior glenohumeral dislocation have also been reported, with the severity ranging from a simple tear to complete detachment. McMahon et al. (2013) reported distinctive capsulolabral lesions, these being a tear of the anteroinferior glenoid labrum in 50% (n=11) of cases. In contrast, Bankart (1923) observed an anterior detachment of the fibrous capsule from the glenoid labrum. The current study observed that the fibrous capsule merges with the glenoid labrum, therefore detachment of the fibrous capsule from the labrum is unlikely to occur: a capsulolabral lesion however is the appropriate description for such lesions.

Several options have been reported to treat anterior glenohumeral dislocation, each of which has advantages and disadvantages. Close reduction, such as the Milch technique (Singh et al., 2012) or Kocher's technique (Ballesteros et al., 2013) have shown adequate recovery, but the Milch technique is recommended in cases not associated with fracture because it is safer, more effective, has less morbidity and is well tolerated. Based on these results the current study concludes that despite the glenoid labrum being affected in anterior glenohumeral dislocation, close reduction still shows good results, emphasizing the healing potential of glenoid labrum tears.

Posterior dislocation:

Posterior dislocation is not common, occurring in only 4% of all dislocations of the glenohumeral joint: the main underlying factor being that the glenoid fossa faces anterolaterally and therefore counteracts any direct posterior force. In addition, infraspinatus and teres minor play a significant role in supporting the joint capsule posteriorly. Although posterior dislocation of the shoulder joint can occur if a posterior thrust along the long axis of the humerus is applied during abduction and medial rotation of the arm (Palastanga et al., 2006; Norman and Harrison, 1963; Nobel, 1969; Eyre-Brook, 1972; Hawkins, 1987; Cicak, 2004; Robinson and Aderinto, 2005; Dlimi et al., 2013): assuming that in this position the humeral head is directed more posteromedial and is therefore more liable to dislocate by applying an external trauma to the anterior aspect of the glenohumeral joint.

Several factors have been reported that cause posterior glenohumeral dislocation. Gopal-Krishnan and Shelton (1972), Eyre-Brook (1972), Hepburn et al. (1989) and Steinmann et al. (2003), O'Connor and Jacknow (1956) and Saupe et al. (2008) have all emphasized that the main reason is a high traumatic load due to seizures; whereas Cicak (2004) state that electric shock and falling on an outstretched hand are the main causative factors. The current study believes that as the glenoid fossa faces anterolaterally and the humeral head posteromedially direct trauma could lead to dislocation of the humeral head posteriorly. Compared to the anterior aspect of the glenohumeral joint the posterior aspect of the fibrous capsule does not have glenohumeral ligaments, its glenoid and humeral versions are anterolateral and posteromedial respectively: yet the incidence of posterior dislocation is far less than anterior with respect to the glenoid notch anteriorly: the posterior glenoid labrum is also thicker and deeper than the anterior. The other difference is the attachment of the fibrous capsule anterosuperiorly: due to the attachment of the superior and middle glenohumeral ligaments the fibrous capsule attaches to the external surface of the glenoid labrum as well as the glenoid bone, while posteriorly the fibrous capsule splits to attach to the internal and external surfaces of the glenoid labrum as well as the glenoid bone giving it much more strength. This could be a contribution to the decreased incidence of posterior dislocation.

Oversen and Sojbjerg (1986b) reported that posterior glenohumeral dislocation was seen in all specimens after complete rupture of the posterior fibrous capsule, as well as teres minor associated with incomplete rupture of the infraspinatus tendon. In contrast, Schwartz et al. (1987) (cited in George et al., 2012) found that incision of the whole posterior fibrous capsule produced posterior subluxation only: posterior dislocation could not be achieved even if the limb was placed in the provocative position predisposing to posterior dislocation because the anterior fibrous capsule and glenohumeral ligaments become tense, counteracting and preventing dislocation. The current study supports Oversen and Sojbjerg (1986b) in that posterior dislocation can be achieved with complete rupture of the posterior fibrous capsule and rotator cuff. The method of Schwartz et al. (1987) could not be ascertained but it appears that an incision was only made in the posterior capsule leaving the rotator cuff intact. In such a method the rotator cuff counteracts the humeral head and could prevent dislocation of the humeral head posterior, furthermore the size of the incision might be insufficient to enable dislocation.

Several studies have reported associated lesions with posterior glenohumeral dislocation in which the glenoid labrum is affected. According to Lin et al. (2013) the reverse Hill-Sachs lesion is always associated with posterior dislocation and was seen in all patients. Nobel (1969) observed that tears of the glenoid labrum or fibrous capsule were associated with posterior dislocation. In contrast, Saupe et al. (2008) disagree stating that in acute first time posterior dislocation reverse Hill-Sachs lesions were observed in 86% (n=31), a reverse Bankart lesion in 31% (n=11), posterior capsuloligamentous complex lesion in 58% (n=21), fracture of the posterior glenoid rim in 31% (n=11) and rotator cuff tear in 42% (n=15). The current study believes that due to the large size and shape of the posterior glenoid labrum it has a high susceptibility to be injured in posterior glenohumeral dislocation, thereby emphasizing its importance in stability.

With improvements in operative techniques and radiology, treatment of posterior dislocation is becoming complex. Close reduction under general anaesthesia and immobilization of the arm in a sling for two and half to three weeks is the treatment of choice (Nobel, 1969; Gopal-Krishnan and Shelton, 1972), leading Cicak (2004) to state that management of posterior dislocation relies on several factors including the size of the defect, its duration, and the age and activity of the individual with treatment ranging from close reduction to joint replacement.

Based on the literature the current study concludes that the contribution of the posterior aspect of the glenoid labrum and fibrous capsule in the treatment of posterior glenohumeral joint dislocation shows successful results. Gopal-Krishnan and Shelton

(1972) support this concept by mentioning that stripping the fibrous capsule extensively followed by immobilization of the arm in flexion and abduction for four weeks is successful because of the strong inferior capsule contraction. Not only in traumatic posterior dislocation but also habitual dislocation the glenoid labrum and fibrous capsule have roles in posterior stability after Eyre-Brook (1972) report that the surgery of choice for habitual dislocation should include a posterior graft attached to the infraspinous fossa, with the fibrous capsule placed between the graft and humeral head: no limitation in the range of motion were noted. Gopal-Krishnan and Shelton (1972) state that appropriate posterior fibrous capsule and soft tissue repair is the treatment for habitual dislocation. Neglecting the posterior glenoid labrum and fibrous capsule manifests in cases of posterior glenohumeral dislocation leading to recurrence; therefore MRI and CT should be prescribed to avoid the risk as well as achieving the best choice of management.

Inferior dislocation:

There is a contrast in the incidence of inferior glenohumeral dislocation, with each basing their conclusion on different reasons. Based on the presence of the rotator cuff tendon anteriorly, superiorly and posteriorly, the coracoacromial ligament superiorly and the lack of support from tendons and muscles inferiorly Faiz and Moffat (2006), Abrahams et al. (2011) Palastanga et al. (2006), Sinnatamby (2006), Moore et al. (2010) and Drake et al. (2005) assume that inferior dislocation is more frequent than in other directions. In contrast, Fery and Sommelet (1987), Yamamoto et al. (2003), Begaz and Mycyk (2006), Dahmi et al. (2008), Groh et al. (2010), Imerci et al. (2013) and Petty et al. (2014) report that it is a rare type constituting about 0.5% of all glenohumeral dislocations, the reason being that it has a specific occurrence mechanism and clinical presentation. During dislocation, the humeral head lies inferior to the glenoid with the humeral shaft directed superiorly and internally rotated. The current study supports Fery and Sommelet (1987), Yamamoto et al. (2003), Begaz and Mycyk (2006), Dahmi et al. (2008), Groh et al. (2010), Imerci et al. (2013) and Petty et al. (2014) for several reasons: (1) based on the literature there are fewer cases reported with posterior glenohumeral dislocation compared to anterior; (2) the mean inferior glenoid labrum thickness and depth provide inferior glenohumeral joint stability; (3) the shape of the inferior glenoid fossa is larger and rounded compared to that superiorly in addition to the superior inclination of the glenoid, in other words the inferior aspect of the glenoid fossa protrudes laterally which in turn could contribute to the prevention of inferior dislocation; and (4) the two bands of the inferior glenohumeral ligaments, the tuberculohumeral ligament as well as the long head of triceps contribute to inferior glenohumeral joint stability.

Dahmi et al. (2008) observed that inferior dislocation is more predominant on the left side and occurs 75% (n=6) in males and 25% (n=2) in females with an average age of 40 years. The present study observed that there was a difference in thickness and depth of the posterior glenoid labrum between males and females, being deeper and thicker in males: however only in thickness was the difference significant. In both genders, the right inferior glenoid labrum was thicker than the left side, which might be the reason why dislocation was predominant on the left side.

A force applied to the humerus with the arm abducted more than 90^0, extended and laterally rotated or an hyper-abduction injury to the arm cause inferior dislocation of the glenohumeral joint (Davison and Orwin, 1996; Begaz and Mycyk, 2006; Kumar et al., 2001; Padgham and Walker, 1996; Dahmi et al., 2008; Petty et al., 2014; Mallon et al., 1990; Yamamoto et al., 2003). As the inferior aspect of the glenoid fossa protrudes laterally as well as the depth of the glenoid labrum make reduction difficult and contribute, with contraction of the rotator muscles, to impaction of the humeral head inferiorly.

Different lesions are associated with the inferior glenohumeral dislocations, these mainly being bony fractures such as of the greater tuberosity, spine of the scapula, the coracoid and acromion processes, and humeral head (Mellon et al., 1990; Davison and Orwin, 1996; Yamamoto et al., 2003; Begaz and Mycyk, 2006; Wang et al., 1992). Soft tissues injuries, such as circumferential tears of the fibrous capsule just lateral to the glenoid labrum, tears of the rotator cuff, ligaments and glenoid labrum (Sarkar et al., 1989; Saseendar et al., 2009; Mallon et al., 1990; Davison and Orwin, 1996; Yamamoto et al., 2003; Sinnatamby, 2006) are also common. The current study observed that the fibrous capsule splits to attach to the internal and external surface of the glenoid labrum, mainly the inferior half, merging together and providing more strength, which in turn could explain the reason why tears of the fibrous capsule occur just lateral to the glenoid labrum.

5.6. Axillary artery, its branches and their variations, suprascapular artery and its variations and venous drainage their variations

5.6.1. Axillary artery and its variations:

The axillary artery commences at the outer border of the first rib as a continuation of the subclavian artery. It passes through the axilla to terminate at the lower border of teres major at the level of the posterior axillary fold to become the brachial artery. The classic arrangement of branches is reported as being: the first part gives the superior thoracic artery; the second part the thoracoacromial and lateral thoracic arteries and the third part the anterior and posterior circumflex humeral arteries as well as subscapular artery (Moore et al., 2011; Palastanga et al., 2006; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922). Variations of the axillary arterial system has been variably reported. Saeed et al. (2002), Kachlik et al. (2011) and Majumdar et al. (2013) consider that these variations are only observed in 3 to 10% (n=7) of individuals. In contrast, Astik and Dave (2012) observed variations in 62.5% (n=16) of shoulders, with the remaining 37.5% (n=9) following standard anatomy textbook descriptions. Hartley and Marquez (2012) support this reporting that in 44% (n=11) of specimens the third part of the axillary artery had variable branches. The current study could not give the incidence in total of the axillary artery variations: with an appreciation of other branches of the axillary artery this study has mainly focused on those branches supplying the glenohumeral joint.

5.6.1.1. The first part of the axillary artery:

Superior thoracic artery:

Classically, the superior thoracic artery is a small branch arising from the anterior aspect of the first part of the axillary artery close to the lower border of subclavius supplying the upper part of the lateral chest wall, subclavius, pectoralis major and minor, serratus anterior as well as the intercostal muscles of the first and second intercostal spaces (Moore et al., 2010; Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946; Robinson, 1922). Chakravarthi et al. (2012) and Troupis et al. (2014) both report two cases in which the artery arises from the second part of the axillary artery. Huelke et al. (1959) state that it arises from the first part of the axillary artery in 86.6% (n=77), the subscapular artery in 5.6% (n=5), the second part of the axillary artery in 2.2% (n=2), the thoracoacromial artery in 1.7% (n=1), the lateral thoracic artery in 1.7% (n=1) and was absent in 2.2% (n=2) of specimens. The current study notes that with respect to the above case studies only one reports the variational incidence of the origin of the superior thoracic artery. As the artery is important in the anastomosis between the axillary and internal mammary arteries further studies should be encouraged. Furthermore, in addition the present study observed a previously unreported ‘new’ artery, named here the ascending glenoid artery, arising from the first part of the axillary artery in 1.8% (n=2). It ascended to reach the superior aspect of the glenoid neck before dividing into several branches supplying the coracoid process from its anterior aspect, the superior aspect of the glenoid rim and glenoid labrum, the coracohumeral ligament and the superior aspect of the fibrous capsule.

5.6.1.2. The second part of the axillary artery:

Thoracoacromial artery:

Variations of the thoracoacromial artery have been reported. Classically the thoracoacromial artery is a short branch arising from the anterior aspect of the second part of the axillary artery just behind the medial border of pectoralis minor, winding around the muscle to appear at its superomedial border. It then passes forward, pierces the clavipectoral fascia and terminates deep to the clavicular head of pectoralis major by giving four branches: acromial, pectoral, clavicular and deltoid (Moore et al., 2011; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922). Several studies have reported different branches of the thoracoacromial artery. According to Astik and Dave (2012) the deltoacromial and clavipectoral arteries arise from the thoracoacromial trunk in 7.5% (n=3). Other branches such as: (1) the lateral thoracic artery can arise from the thoracoacromial artery (Moore et al., 2011; Moore et al., 2010; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922); (2) the superior thoracic artery has been reported to arise from the thoracoacromial artery (Huelke et al., 1959). A double thoracoacromial artery has also been reported (Daimi et al., 2010). The current study did not observe a double thoracoacromial artery. The thoracoacromial artery has an important role in supplying the sternoclavicular joint and mammary glands, therefore its variations should be well known to surgeons. Nevertheless, it is concluded that further studies are required to evaluate variations of the thoracoacromial artery and its branches.

Origin:

From the first part of the axillary artery:

The thoracoacromial artery has been reported arising from the first part of the axillary artery, but there are differences in its origin. According to Daimi et al. (2010) it arises directly from the first part of the axillary artery. Huelke et al. (1959) agree stating that it arises from the first part of the axillary artery in 29.8% (n=27), the second part in 68.5% (n=61) and the lateral thoracic/subscapular/brachial artery in 0.6% (n=1): it was observed to be absent in 1.1% (n=1). The thoracoacromial artery is also reported to arise indirectly from the first part of the axillary artery, either from a common trunk (Saralaya et al., 2008; Goldman et al., 2012) or from the subscapular artery (Goldman, 2008). In the current study, an origin of the thoracoacromial artery, either directly or indirectly from the first part of the axillary artery, was not observed.

From the second part axillary artery:

Classically the thoracoacromial artery arises from the second part of the axillary artery (Moore et al., 2011; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922). However, variations in its origin from the second part are also observed such as: (1) indirectly from the second part of the axillary artery through either a common trunk (Srimathi, 2011) or from regular and variant branches of a bifid axillary artery (Jurjus et al., 1999); (2) being the only branch of the second part of the axillary artery (Agrawal et al., 2013; Jain et al., 2013); (3) being absent (Chitra and Anandhi, 2013; Huelke et al.,1959). The current study does not support the observations of Agrawal et al. (2013) or Jain et al. (2013) because the ascending glenoid branch arose from the second part of the axillary artery in the majority of shoulders, as well as unnamed muscular branches always being seen. Therefore, the thoracoacromial artery cannot be the only branch arising from the second part of the axillary artery. The current study observed that the thoracoacromial artery arises from the second part of the axillary artery as a single or common trunk with other branches or from the medial trunk of the axillary artery.

From the third part axillary artery:

The thoracoacromial artery has also been observed to arise indirectly from the third part of the axillary artery. According to Troupis et al. (2014) it arises from the deep trunk of the third part of the axillary artery. Pant et al. (2013) have reported that the third part of the axillary artery can trifurcate into thoracoacromial, lateral thoracic and subscapular arteries. The current study concurs with the literature observing that the incidence of the thoracoacromial artery arising from the third part of the axillary artery is less than from the first part: a thoracoacromial artery arising from the third part of the axillary artery was not observed.

Lateral thoracic artery:

The lateral thoracic artery arises from the anterior aspect of the second part of the axillary artery just behind the lateral margin of pectoralis minor. It descends along the lateral (axillary) border of pectoralis minor giving branches to the breast, as well as muscular branches to the pectoral muscles, the axillary lymph nodes and superficial fascia of the superior part of the abdominal wall. It anastomoses with the intercostal, subscapular and pectoral branch of the thoracoacromial arteries (Moore et al., 2011; Moore et al., 2010; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922). The current study agrees that in the majority the lateral thoracic arteries arises from the second part of the axillary artery and follows the classical course. Majumdar et al. (2013) are the only authors who report absence of the lateral thoracic artery. The lateral thoracic artery was seen in all cadavers in the present study.

Other branches from the lateral thoracic artery have been reported. Huelke et al. (1959) state that it can give the superior thoracic artery, while Farhan and Selman (2010) report that it gives the subscapular and posterior circumflex humeral arteries in 7% (n=2) and 2% (n=1), respectively. In contrast, Olinger and Benninger (2010) reported that it gave the subscapular artery in 5.4% (n=2), the thoracodorsal in 7.2% (n=6) and the posterior circumflex humeral artery in 1.2% (n=1).

The current study could not support Farhan and Selman (2010) as an origin of the subscapular and posterior circumflex humeral artery from the lateral thoracic artery was not observed.

Origin:

From the first part of the axillary artery:

The lateral thoracic artery has been reported to arise directly from the first part of the axillary artery (Daimi et al., 2010; Durgun et al., 2002) or indirectly either via a common trunk (Goldman et al., 2012), or from the lateral trunk of the axillary artery (Yotova and Novakov, 2004) or from an early origin of the subscapular artery (Lee and Kim, 2008; Goldman, 2008; Saralaya et al., 2008). Huelke et al. (1959) support this also stating that it arises either directly or indirectly from the first part of the axillary artery in 1.7% (n=2). The current study did not observe an early origin of the lateral thoracic artery.

From the second part of the axillary artery:

Classically, the lateral thoracic artery arises from the second part of the axillary artery as a single branch; however variations in its origin have been reported. Only one case report mentions the lateral thoracic artery arising indirectly from one of the two divisions of the second part of the axillary artery (Chakravarthi et al. 2012), or from the subscapular artery which arises from the second part of the axillary artery (Swamy et al., 2013; Majumdar et al. 2013). In contrast, several case reports have observed it arising from the common trunk of the second part of the axillary artery (Baral et al., 2009; Mehrdad and Sadeghi, 2007; Shantakumar and Mohandas Rao, 2012; Chitra and Anandhi, 2013; Srimathi, 2011 Patnaik et al., 2000). The current study observed few cases in which the lateral thoracic artery arose from the second part of the axillary artery from a common trunk. As most previous studies are case reports the incidence of these variations remains unknown.

From the third part of the axillary artery:

Variation in the origin of the lateral thoracic artery from the third part of the axillary artery has been observed. Pant et al. (2013), Agrawal et al. (2013) Jain et al. (2013)

Sarkar et al. (2014) Bolwar (2011), Satyanarayana et al. (2012) all report that the lateral thoracic artery arose from a common trunk of the third part of the axillary artery. In contrast, Astik and Dave (2012), Majumdar et al. (2013) and Troupis et al. (2014) observed it arising from the subscapular artery. Olinger and Benninger (2010) and Farhan and Selman (2010) state that the lateral thoracic artery arises from the subscapular artery with incidence 4.2% (n=3) to 5% (n=1). Huelke et al. (1959), however report that the lateral thoracic artery arose from the third part of the axillary artery or its branches (subscapular or thoracodorsal artery) in only 1.7% (n=2) of specimens. The current study did not observe an origin of the lateral thoracic artery from the third part of the axillary artery. As the lateral thoracic artery is also important in supplying the breast surgeons should be aware of its variations: unfortunately the majority of the literature consists of case reports.

The current study does not support the view that there are only two branches arising from the second part of the axillary artery. The ascending glenoid artery was found to arise from the superior aspect of the second part of the axillary artery in 92.50% (n=130) of cadavers supplying the superior aspect of the rotator cuff, coracohumeral ligament, the superior aspect of the fibrous capsule, the origin of the long head of biceps, the superior and anterosuperior aspects of the glenoid labrum, and subscapularis. The current study suggests that as this artery is important in supplying the superior and anterior aspects of the glenoid labrum, in addition to the adjacent structures, surgeons should be aware of its presence during any axillary or open glenohumeral joint surgery. Furthermore, reclassification of the branches of the axillary artery should be considered.

5.6.1.3. The third part of the axillary artery:

Posterior circumflex humeral artery:

Origin:

First part of the axillary artery:

The posterior circumflex humeral artery has been observed to arise either directly or indirectly from the first part of the axillary artery. Saralaya et al. (2008), Goldman et al. (2012) and Lee and Kim (2008) report it arising indirectly from the first part of the axillary artery via the subscapular artery: Lee and Kim (2008) add that the posterior circumflex humeral artery can also arise directly from the first part of the axillary artery. Yotova and Novakov (2004) partly agree that the posterior circumflex humeral artery indirectly arises from the first part of the axillary artery, but it was via a medial trunk of the two division of the first part of the axillary artery. The current study supports this observing that the posterior circumflex humeral artery arose indirectly from the first part of the axillary artery via either the lateral or deep trunk; however it was not observed to arise directly from the first part of the axillary artery.

Second part of the axillary artery:

The posterior circumflex humeral artery has also been reported to arise either directly or indirectly from the second part of the axillary artery. Indirectly by Durgun et al. (2002) who reported it arising from the second part of the axillary artery via the subscapular, and Yohannan and Ravindran (2013) who observed it from its deep trunk. In contrast, Verma et al. (2014) state that it arises from the second part via a collateral branch. Swamy et al. (2013), Chitra and Anandhi (2013), Arquez (2014), Baral et al. (2009), Chakravarthi et al. (2012), Patnaik et al. (2000) and Srimathi (2011) all report it arising directly from the second part of the axillary artery as a common trunk with other branches. Farhan and Selman (2010) observed it arising from the lateral thoracic in 2% (n=1) of specimens. The current study did not observe the posterior circumflex humeral artery arising either directly or indirectly from the second part of the axillary artery.

Third part of the axillary artery:

The incidence and origin of the posterior circumflex humeral artery arising from the third part of the axillary artery is variable. Classically, it arises from the lateral aspect of the third part of the axillary artery behind the origin of the anterior circumflex humeral artery (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946). However, according to Hartley and Marquez (2012) only in 56% (n=13) does the third part of the axillary artery give rise to the classical branches, noting that this was more common in males (71.42%) and on the right side (80%). Farhan and Selman (2010) state that the posterior circumflex humeral artery arises from the third part of the axillary artery in 77% (n=20). Olinger and Benninger (2010) partly agree reporting that it arises directly from the axillary artery in 77.1% (n=64) (87.5% bilateral), the circumflex scapular artery in 12% (n=10) (40% bilateral), the deep brachial artery in 8.4% (n=7) (71.4% bilateral) and the lateral thoracic artery in 1.2% (n=1). Patnaik et al. (2000) observed the posterior circumflex humeral artery arising from the third part of the axillary artery in 96% (n=24) of specimens (as a single branch in 58% (n=14) and as a common origin with the subscapular and anterior circumflex humeral in 22% (n=5) and 16% (n=4) respectively). Hattori et al. (2013) disagree stating that the subscapular and posterior circumflex humeral arteries follow the classical branching pattern in 33.9% (n=21), suggesting that variations of the subscapular and posterior circumflex humeral arteries are as high as 66.1% (n=41). In the current study the incidence of the posterior circumflex humeral artery arising from the third part of the axillary artery was similar to Olinger and Benninger (2010) and Farhan and Selman (2010), being 75.7% (n=106). The reason that Pantnaik et al. (2000) reported a higher incidence could be due to sample size (only 25 cadavers), while Hattori et al. (2013) stated a lower incidence because they based their finding on multidetector-row computed tomography angiography.

The origin of the posterior circumflex humeral artery from the third part of the axillary artery is diverse: however few studies have reported it arising from the subscapular artery. Saeed et al. (2002) observed a common subscapular circumflex humeral trunk bilaterally (3.8%, n=2) arising from the third part of the axillary artery giving double posterior circumflex humeral and subscapular arteries. Majumdar et al. (2013) reported the right side posterior circumflex humeral artery originating from the subscapular artery. However, Garry and Marquez (2008) report that the posterior circumflex humeral artery arises from either the subscapular or thoracoacromial artery in only 6.53% (n=3) of cases: Farhan and Selman (2010) disagree stating that it arises from the subscapular in 11% (n=3). The current study agrees that the posterior circumflex humeral artery can arise from the subscapular artery, but disagrees with Garry and Marquez (2008) and Farhan and Selman (2010) stating that the incidence is 8.6% (n=12). Furthermore, the current study is the first to observe the posterior circumflex humeral artery arising from the circumflex scapular artery in 1.4% (n=2) of shoulders. No variations were observed in its course; it follows the classical course.

The posterior circumflex humeral artery arising from the third part of the axillary artery as a common trunk has been widely observed. Naveen et al. (2014), Chauhan et al. (2013), Bagoji et al. (2013), Shashikala and Panjakash (2012), Rao et al. (2008), Satyanarayana et al. (2012), Majumdar et al. (2013), Kachlik et al. (2011), Sarkar et al. (2014), Jain et al. (2013), Pant et al. (2013) and Agrawal et al. (2013) all report it arising from the third part of the axillary artery as a common trunk. The incidence of the posterior circumflex humeral artery has been quantified, with Karambelkar et al. (2011), Astik and Dave (2012) and Huelke et al. (1959) stating that it arises as a common trunk in 8.33% (n=2) to 20% (n=6) of cases.

The posterior circumflex humeral artery has also been seen to arise from rare branches of the axillary artery. According to Soubhagya et al. (2006) it arose indirectly from the third part of the axillary artery via the lateral trunk. The current study agrees with Soubhagya et al. (2006) observing that it can arise from the lateral division of the axillary artery. Sargolzaei-Aval and Arab (2013), Sawant et al. (2012b), VijayaBhaskar et al. (2006), Desai et al. (2011), George et al. (2007), Cavdar et al. (2000) and Troupis et al. (2014) have stated that it arises indirectly from the third part of the axillary artery through the deep trunk. Patnaik et al. (2001) observed it arising indirectly from the third part of the axillary artery via the second branch of the third axillary artery. Venieratos and Lolis (2001) reported a right axillary artery giving a collateral branch which in turn gave rise to the subscapular, anterior and posterior circumflex humeral, profunda brachii and ulnar collateral arteries. Based on this, the current study concludes that the findings of Venieratos and Lolis (2001) Patnaik et al. (2001) are similar to those of others: the authors have used different descriptions, such as second branch and collateral branch, instead of medial and lateral or superficial and deep trunks. The current study also supports Sargolzaei-Aval and Arab (2013), Sawant et al. (2012b), VijayaBhaskar et al. (2006), Desai et al. (2011), George et al. (2007), Cavdar et al. (2000) and Troupis et al. (2014) by finding that the posterior circumflex humeral artery can arise indirectly from the third part of the axillary artery via its deep trunk.

Other origins:

Other rare variations in origin have also been reported. Salpek et al. (2007) and Kachlik et al. (2011) observed the posterior circumflex humeral artery arising from the profunda brachii in the axilla as a common trunk with the anterior circumflex humeral artery or from a common trunk of the axillary artery. Farhan and Selman (2010) reported that it arises from the brachial artery in 9% (n=2). The current study is the first to observe the posterior circumflex humeral artery arising from the profunda brachii artery in the posterior aspect of the arm, with an incidence of 2.1% (n=3). It then ascends between the long and lateral heads of triceps to reach the posteroinferior aspect of the glenohumeral joint to ramify in deltoid.

Numbers:

Few studies have reported more than one posterior circumflex humeral artery, each of which has a different origin. According to Jurjus et al. (1999) double posterior circumflex humeral arteries arose from the third part of the normal and variant branches of the axillary artery. Astik and Dave (2012) have also reported a double posterior circumflex humeral artery, but originating from the third part of the axillary artery and brachial artery: this was observed in 2.94% (n=1) of specimens. Whereas Saeed et al. (2002) observed a bilateral common subscapular circumflex humeral trunk in 3.8% (n=2) arising from the third part of the axillary artery giving double posterior circumflex humeral and subscapular arteries. A double posterior circumflex humeral artery was not observed in the current study.

Site:

Classically the posterior circumflex humeral artery arises from the lateral aspect of the third part of the axillary artery behind the origin of the anterior circumflex humeral artery and passes posterolateral to the anatomical neck of the humerus (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946). Rao et al. (2012) state that it arises from the lower border of the third part of the axillary artery and passes through the lower triangular space before passing upwards and laterally to reach the surgical neck of the humerus. Konarik et al. (2009) report a posterior circumflex humeral artery arising from the axillary artery at the distal end of pectoralis major then running deep to latissimus dorsi and teres major to supply the shoulder joint. The current study found that the posterior circumflex humeral artery can arise at the level of the lower border of subscapularis from the third part of the axillary artery or from its branches, and at the level of the spiral groove when it arises from the brachial or profunda brachii arteries. Furthermore, and for the first time, the current study reports that the posterior circumflex humeral artery arises from the posterior (44.3%, n=62), lateral (19.3%, n=27), superior (2.9%, n=4), posterolateral (31.4%, n=44), inferolateral (1.4%, n=2) and posteromedial (0.7%, n=1) aspect of the artery

Size and length:

To the author's knowledge, parameters of the posterior circumflex humeral artery have not been previously reported. In anatomical textbooks, the anterior circumflex humeral artery is said to be smaller than the posterior circumflex humeral artery (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946; Robinson, 1922). However, in contrast the current study found that the posterior circumflex humeral artery has a variable diameter and length, with an average diameter of 3.98 mm (range 1.18 – 7.37 mm) and length of 67.11 mm (range 47.48 – 92.3 mm).

Course and branches:

Classically, the posterior circumflex humeral artery runs posterolateral through the quadrangular space accompanied by the axillary nerve and posterior circumflex humeral vein to wind around the surgical neck of the humerus from its posterior aspect supplying the glenohumeral joint, nutrient branches to the humerus, and muscular branches to the long head of triceps, teres minor and deltoid (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946; Robinson, 1922). The current study classified branches of the posterior circumflex humeral artery into stages depending on its course as it is easier to understand and follow. Firstly, before passing through the anatomical triangle it gives muscular branches to teres major, latissimus dorsi and subscapularis. Secondly, in the anatomical triangle it gives (i) muscular branches to the long head of triceps, (ii) nutrient branches to the medial side of the upper end of the humeral shaft 15 – 25 mm inferior to the surgical neck: these branches also supply the anteroinferior and inferior aspect of the anatomical neck, and (iii) capsular branches which pass through the fibrous capsule from its anteroinferior and inferior aspects running for variable distances before entering the joint: these branches also supply subscapularis, the glenohumeral ligaments and fibrous capsule. Passing medially through the fibrous capsule the branches supply the inferior and posteroinferior aspects of the glenoid labrum. Thirdly, after the anatomical neck it gives (i) periosteal branches to the posterior aspect of the upper 1/3rd of the shaft of the humerus, (ii) muscular branches to deltoid, the long head of triceps, teres minor and teres major, (iii) capsular branches pass through the posterior and posteroinferior aspects of the fibrous capsule of the shoulder joint supplying it, teres minor and the inferoposterior and posterior aspects of the anatomical neck, and (iv) nutrient branches to the greater tuberosity and adjacent bone as well as to the posterior aspect of the surgical neck.

The current study adds to the literature in that the posterior circumflex humeral artery can give the profunda brachii in 2.85% (n=4) and the anterior circumflex humeral artery in 12.14% (n=17). Furthermore, for the first time it is reported that the inferior glenoid artery arises from the posterior circumflex humeral artery in 29.9% (n=35). The inferior glenoid artery passes through the inferior aspect of the fibrous capsule and divides into branches before piercing the inferior region of the glenoid labrum between 5 and 7 o'clock supplying it. The branch supplies subscapularis, the inferior aspect of the fibrous capsule and terminates in the glenoid labrum at 6 o'clock. It is important to emphasize the variations of the posterior circumflex humeral artery and its branches in detail for a number of reasons: (1) it could help to amend what has been written in anatomy textbooks as almost 25% of posterior circumflex humeral arteries do not arise from the third part of the axillary artery, (2) for clinical and surgical purposes, such as in glenohumeral joint surgery in general or the glenoid labrum in particular, or surgery of the axilla.

Subscapular artery:

In anatomy textbooks the subscapular artery is considered to be the largest branch of the axillary artery and the major blood supply of the posterior axillary wall. It arises from the posterior aspect of the third part of the axillary artery running along the inferior border of subscapularis for 2 – 3 cm before terminating as two main branches: the circumflex scapular and thoracodorsal arteries (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922). Patnaik et al. (2000) have drawn attention to the fact that the variability of origin of the subscapular artery is as high as 80% (n=20), arising either directly as a single artery from the third part of the axillary artery (58%, n=14), or as a common trunk with the posterior circumflex humeral artery (18%, n=4), profunda brachii (2%, n=1), or deep division of the brachial artery (2%, n=1), while in the remaining 20% (n=5) the subscapular artery arises from the first part of the axillary artery in 16% (n=4) and is absent in 4% (n=1). Recently Hattori et al. (2013) observed that the subscapular and posterior circumflex humeral arteries follow the classical branching pattern in 33.9% (n=21), suggesting that variations of both arteries are as high as 66.1% (n=41). However, Garry and Marquez (2008) disagree reporting that 82.6% (n=38) of subscapular arteries follow the classical anatomical pattern by arising from the posterior aspect of the third part of the axillary artery and dividing into circumflex scapular and thoracodorsal arteries. They also add that the posterior circumflex humeral artery arose from either the subscapular or thoracodorsal artery in only 6.53% (n=3).Rowsell et al. (1984) reported that the subscapular-thoracodorsal arterial system was persistent in all specimens examined. The current study observed that the subscapular artery arose from the inferior border of the subscapularis from the third part of the axillary artery in 88.6% (n=124) of specimens, the first part of the axillary artery in 10.70% (n=15) and the profunda brachii artery in 0.7% (n=1). It also arose from the medial (68.60%, n=96), posteromedial (16.40%, n=23), inferomedial (0.70%, n=1), inferior (9.3%, n=13) or posterior aspect of the axillary artery (5%, n=7) and descended slightly posterior to run on the lateral border of the scapula as far as the inferior angle.

The diameter of the subscapular artery has been reported only in three studies. Jesus et al. (2008), Yotova and Novakov (2004) and Saeed et al. (2002) report the diameter to be 4 – 5 mm. The current study found the overall mean length (the subscapular and thoracodorsal artery is measured as one artery) and diameter to be 94.46 mm and 5.20 mm, with the mean length and diameter in males and females being 96.97 and 5.52 mm and 92.57 and 4.97 mm respectively.

Absence of the subscapular artery has been reported by Salpek et al. (2007) and Khaki et al. (2011), with the latter authors adding that the circumflex scapular artery arises directly from the third part of the axillary artery. Patnaik et al. (2000) report that it was absent in 4% (n=1), while Olinger and Benninger (2010) state an incidence of 2.4% (n=2) disagreeing with Khaki et al. (2011) by stating that the circumflex scapular and thoracodorsal arteries arise from the lateral thoracic artery. Jesus et al. (2008) report that the subscapular artery is present in 96.7% (n=58). The current study observed the subscapular artery in all specimens studied.

Origin:

From the first part of the axillary artery:

The subscapular has been observed variably arising from the first part of the axillary artery. Saralaya et al. (2008) reported specimens where the second and third parts of the axillary artery did not give any branches while the first part gave the superior thoracic artery and a large collateral branch they named the common subscapular trunk. Goldman et al. (2012) support this reporting a common trunk arising from the first part of the axillary artery giving rise to the thoracoacromial and subscapular arteries. Earlier Goldman (2008) observed that the subscapular artery arose directly from the first part of the axillary artery giving origin to the thoracoacromial, posterior circumflex humeral and lateral thoracic arteries. Lee and Kim (2008) partly agree reporting a bilateral variation of the subscapular artery arising from the first part of the axillary artery: one side it branched into the lateral thoracic, thoracodorsal and a large posterior circumflex humeral, which later gave the circumflex scapular artery, while on the other it gave the lateral thoracic, thoracodorsal and circumflex scapular arteries. Durgun et al. (2002) agree that the first part of the axillary artery can give the subscapular artery. On the other hand Yotova and Novakov (2004) reported a rare variation of the first part of the axillary artery bifurcating into lateral and medial branches, with the lateral branch giving the lateral thoracic artery then continued in the arm as the brachial artery, while the medial branch descended and at the lower border of pectoralis minor gave the subscapular and anterior and posterior circumflex humeral arteries following which it passed into the arm as the profunda brachii. Based on these finding the current study concludes that the origin of the subscapular artery shows three anatomical variations: firstly, it can arise as a common trunk, secondly as a single trunk and thirdly from the lateral branch of the two division of the axillary artery. Furthermore, the present study agrees with Goldman (2008) and Lee and Kim (2008) in which the subscapular can arise directly as a single trunk from the inferior aspect of the first part of the axillary artery with an incidence of 10.7% (n=15). It then runs downward and laterally to reach the inferior angle of the scapula. The circumflex scapular artery can arise from the posterior circumflex humeral artery or the third part of the axillary artery.

From the second part of the axillary artery:

The origin of the subscapular artery from the second part of the axillary artery does so via a number of variations. Daimi et al. (2010) and Majumdar et al. (2013) report that it arises directly from the second part of the axillary artery, as do Swamy et al. (2013), following which it gives rise to the subscapular artery which bifurcates into the posterior circumflex humeral and lateral thoracic arteries. Durgun et al. (2002) partly agree stating that the subscapular artery arises from the medial side of the second part of the axillary artery and gives the posterior circumflex humeral, thoracodorsal and circumflex scapular arteries. The present study confirms that there is no direct origin of the subscapular artery from the second part of the axillary artery.

Several studies have reported the subscapular artery arising from a common trunk of the second part of the axillary artery, but not with the same branches. Arquez (2014) observed a common trunk giving the thoracodorsal, circumflex scapular, subscapular and posterior circumflex humeral arteries. Baral et al. (2009) stated similar results except they found the lateral thoracic instead of the posterior circumflex humeral artery. Srimathi (2011) reported a common trunk which gave rise to the thoracoacromial, lateral thoracic, subscapular and posterior circumflex humeral arteries. Saeed et al. (2002) and Chitra and Anandhi (2013) both observed a common trunk giving rise to the subscapular, lateral thoracic and posterior circumflex humeral arteries. Both Shantakumar and Mohandas Rao (2012) and Mehrdad and Sadeghi (2007) reported a common trunk which bifurcated into lateral thoracic and subscapular arteries. Chakravarthi et al. (2012) in contrast observed two main trunks the first of which gave the superior thoracic, clavicular and pectoral branches and the second the lateral thoracic, posterior circumflex humeral, thoracodorsal, and subscapular branches before continuing as the circumflex scapular artery. According to Verma et al. (2014) the second part of the axillary artery gives rise to three branches: thoracoacromial, subscapular, which bifurcates into the circumflex scapular and thoracodorsal arteries, and a collateral branch, giving rise to both the anterior and posterior circumflex humeral arteries as well as accessory subscapular arteries. The present study did not observe any of these variations, with no common trunk being observed.

Furthermore, not only does the subscapular artery not arise from the second part of the axillary artery, nor do any of its branches. According to Farhan and Selman (2010) the subscapular artery arose from the lateral thoracic artery in 7% (n=2) of specimens, with Olinger and Benninger (2010) observed it arising from the lateral thoracic artery in 5.4% (n=2). The current study does not support these observations of the subscapular artery arising from branches of the second part of the axillary artery. Based on the findings of the current study it is concluded that: (1) as the majority of reports are case studies the incidence of the subscapular artery arising from the second part of the axillary artery is not clear; (2) the subscapular artery arises from the second part of the axillary artery in one of three ways - directly, from one of its branches, and from a common trunk with other branches, with the latter considered to be the most common; (3) all the case reports are different, agreeing that the subscapular artery arises from a common trunk but differ on their branches.

The incidence of the subscapular artery arising directly from the second part of the axillary artery has been quantified in only two studies. According to Samata Gaur et al. (2012) 12% (n=6) of specimens show variations of the second part, in which 6% (n=3) had 3 extra branches (alar branches) and 4% (n=2) give the subscapular artery. Karambelkar et al. (2011) report the subscapular arising from the second part of the axillary artery in 6.66% (n=2) (50% on each side). In contrast, Jesus et al. (2008) found that it arises from the second part of the axillary artery in 15% (n=9). The incidence shows variability with the highest reported being by Jesus et al. (2008); however despite this the subscapular artery did not arise from the second part of the axillary artery in the current study.

From the third part of the axillary artery:

Classically the subscapular artery arises as a single branch directly from the third part of the axillary artery (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922). According to Jesus et al. (2008) it arises from the third part in 76.7% (n=46). Whereas the current study observed that the subscapular artery arose from the third part of the axillary artery in 88.60% (n=124).

Several studies have reported the subscapular artery arising indirectly from the third part of the axillary artery, but each with variations.

Common trunk:

Many cases studies report the subscapular artery arising from a common trunk of the third part of the axillary artery, but the majority give different accompanying branches. According to Kachlik et al. (2011) the third part of the axillary artery divides into the brachial artery and a common trunk which gives the anterior and posterior circumflex humeral, subscapular and circumflex scapular arteries. Whereas Rao et al. (2008) mention that the third part of the axillary artery has a common trunk which gives rise to the subscapular, anterior and posterior circumflex humeral, profunda brachii and ulnar collateral arteries. Naveen et al. (2014) partly agree stating that a common trunk arising from the third part of the right axillary artery gives the subscapular, anterior and posterior circumflex humeral arteries and then continues as the profunda brachii in the arm. Bolwar (2011) observed a common trunk of origin giving rise to the lateral thoracic and subscapular arteries. Sarkar et al. (2014) and Agrawal et al. (2013) partly agree stating that the third part gives the anterior circumflex humeral artery and a common trunk, which divides into the posterior circumflex humeral artery, lateral thoracic and subscapular arteries. Jacquemin et al. (2001) mention that the subscapular artery arises from a common origin with the ulnar artery. The current study observed that the subscapular artery arose from a common trunk with: (1) posterior circumflex humeral artery; or (2) the posterior circumflex humeral artery and profunda brachii; or (3) the anterior circumflex humeral artery only.

Superficial and deep or medial and lateral trunks:

According to Cavdar et al. (2000), Sawant et al. (2012b) and Yohannan and Ravindran (2013) the superficial trunk descends in the arm as the brachial artery, whereas the deep trunk trifurcates into the subscapular, and anterior and posterior circumflex humeral arteries. Desai et al. (2011), George et al. (2007), Sargolzaei-Aval and Arab (2013) and Troupis et al. (2014) reported similar variations with the profunda brachii or the thoracoacromial artery as the fourth branch. In contrast, VijayaBhaskar et al. (2006) report that the deep branch of the axillary artery gives the subscapular artery only. On the other hand, Pandey et al. (2004) observed the subscapular artery to arise persistently from the medial division of the axillary artery, as did Soubhagya et al. (2006). Patnaik et al. (2001) have also reported the third part of the axillary artery dividing into two branches, the first of which passes into the forearm as the radial artery, while the second gives the anterior and posterior circumflex humeral, subscapular and profunda brachii arteries. Venieratos and Lolis (2001) observed an axillary artery giving a collateral branch which in turn gave rise to the subscapular, anterior and posterior circumflex humeral, profunda brachii and ulnar collateral arteries. Based on these observations the current study concludes that the origin of the subscapular artery from the deep or medial or second or collateral trunk is all studies similar but with different descriptions. Nevertheless, the main principle is that the third part of the axillary artery divides into two trunks each of which gives different branches. Furthermore, the current study partly agrees with Patnaik et al. (2001) that the third part of the axillary artery divides into two superficial and deep trunks, with the deep trunk giving the anterior and posterior circumflex humeral and subscapular arteries then terminates as the profunda brachii artery.

The incidence of variations of the subscapular artery arising from the third part of the axillary artery has been quantified in several studies, but differences exist. Samata Gaur et al. (2012) report that in 20% (n=5) a common trunk gave rise to the subscapular and posterior circumflex scapular arteries, while Astik and Dave (2012) reported a common trunk giving rise to the anterior and posterior circumflex humeral, subscapular and profunda brachii arteries in 12.5% (n=5) of specimens. Karambelkar et al. (2011) observed a common trunk which bifurcated into posterior circumflex humeral and subscapular arteries in 8.33% (n=2) of specimens. Saeed et al. (2002) observed a common subscapular circumflex humeral trunk bilaterally in 3.8% (n=2) arising from the third part of the axillary artery giving double posterior circumflex humeral and subscapular arteries. Hartley and Marquez (2012) found that only 56% (n=13) of the third part of the axillary artery gave rise to the classical branches: subscapular, anterior and posterior circumflex humeral arteries, with the profunda brachii and both the anterior and posterior circumflex humeral arteries arising from the subscapular artery in 6% (n=1). The current study observed that the subscapular artery arose as common origin with the posterior circumflex humeral artery in 57.44% (n=27/47), or with the posterior circumflex humeral and profunda brachii in 4.25% (n=2/47) or with the anterior circumflex humeral artery in 2.12% (n=1/47).

Branches:

The subscapular artery terminates as the circumflex scapular and thoracodorsal arteries (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922). However, Majumdar et al. (2013) state that it gives the posterior circumflex humeral and lateral thoracic arteries. Farhan and Selman (2010) agree also stating that the subscapular artery gives the lateral thoracic and posterior circumflex humeral arteries in 5% (n=1) and 11% (n=3) respectively. De Paula et al.

(2013) observed the subscapular artery to give the profunda brachii artery, while Astik and Dave (2012) the lateral thoracic artery. The current study agrees with Majumdar et al. (2013) adding that in 8.6% (n=12) of specimens the subscapular artery gave the posterior circumflex humeral artery. Furthermore, the current study observed that the subscapular artery gives the inferior glenoid artery in 15.4% (n=18).

Circumflex scapular artery:

Course:

In anatomy textbooks the circumflex scapular artery is one of two terminal branches of the subscapular artery, which itself arises from the third part of the axillary artery. It winds round the lateral border of the scapula leaving the axilla through the triangular space to gain access to the posterior scapular region where it contributes to the anastomoses around the scapula (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922). The current study confirms that the subscapular artery curves posteriorly to pass through the triangular space then downwards for 30 – 40 mm before curving posteriorly to run between teres minor anteriorly and teres major posteriorly, ending by ramifying in infraspinatus to share in the anastomoses around the scapula. Branches given in the triangular space are an infrascapular branch to the subscapular fossa which anastomoses with branches from the transverse cervical and transverse scapular arteries. It also gives a branch which descends along the lateral border of the scapula as far as the inferior angle, in addition to muscular branches to teres minor, teres major and deltoid (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Smith et al., 1983; Johnston and Whillis, 1946; Robinson, 1922). Branches of the circumflex scapular artery are not well documented; therefore, the current study considers these in detail in the order in which they arise along its course from origin to termination. The first branch is the inferior glenoid artery which was present in 54.70% (n=64) and had a mean length and diameter of 28.81mm and 1.16 mm respectively. It runs superiorly passing through subscapularis to reach the distal attachment of the inferior aspect of the fibrous capsule of the glenohumeral joint then passes through the inferior aspect of the capsule before dividing into branches piercing the inferior region of the glenoid labrum between 5 and 7 o'clock supplying it. This branch supplies subscapularis, the inferior aspect of the fibrous capsule and terminates in the glenoid labrum. The second branch is a muscular branch arising 30 mm from its origin and passes inferomedially undercover of subscapularis supplying it at the middle of its lateral border. The third branch arises 30 mm from the origin and runs deep to subscapularis as far as 30 mm from the inferior aspect of the glenoid rim. At the anterior ridge of the lateral border this branch divides into three (superior, middle and inferior). The superior branch runs superiorly to within 30 mm of the anterior glenoid rim then curves medially and ramifies as muscular, nutrient and periosteal branches in the upper 1/3rd of the subscapular fossa. As the artery curves close to the shoulder joint it gives periosteal branches to supply the anterior, anteroinferior and anterosuperior aspects of the glenoid rim and glenoid labrum. The middle (infrascapular) branch runs medially to the middle of the subscapular fossa where it supplies subscapularis and the subscapular fossa. The inferior branch runs inferomedially to supply the lower 1/3rd of the subscapular fossa and subscapularis. The fourth branch is a nutrient branch which arises 30 mm from its origin at the anterior aspect of the lower border of the origin of the long head of triceps: it descends inferiorly for 15 mm before penetrating the lateral border of the scapula. The fifth branch is a muscular branch which arises 30 mm from its origin running for a short distance on the lower border of the long head of triceps then ramifying in it. The sixth branch arises from the circumflex scapular artery about 30 mm from the inferior border of the long head of triceps and descends 30 – 35 mm on the lateral border of the scapula terminating close to the inferior angle by supplying subscapularis and the lateral border of the scapula. The seventh branch, present in 74.42% (n=104) of specimens, had a mean diameter of 2.99 mm. It is named an ascending branch arising from the circumflex scapular artery 30 mm from its origin, at the lower border of the origin of the long head of triceps. It ascends superomedially, passing posterior to the origin of the long head of triceps and grooves the bone for a short distance accompanied by two veins (sometimes one), towards the inferior aspect of the spinoglenoid notch, then curves medially to run in the infraspinous fossa just inferior to the root of the spine of the scapula terminating by giving several superior and inferior branches supplying infraspinatus, teres minor and the infraspinous fossa. Its branches are: (1) at the inferior aspect of the spinoglenoid foramen a branch which runs on the posteroinferior aspect of the fibrous capsule supplying the glenoid rim, fibrous capsule and glenoid labrum; (2) at the inferior aspect of the spinoglenoid notch an ascending branch which runs through the spinoglenoid notch, lateral to the suprascapular vessels, then to the supraspinous fossa giving nutrient branches to the inferior aspect of the acromion process, acromioclavicular joint, muscular branches to supraspinatus, nutrient branches to the superior aspect of the glenoid neck and a small branch, via the suprascapular notch, to the subscapular fossa; (3) nutrient branches to the posteroinferior aspect of the glenoid neck and glenoid rim; (4) muscular branches to infraspinatus and teres minor; and (5) periosteal and nutrient branches supplying the infraspinous fossa and inferior aspect of the root of the spine of the scapula. In the posterior approach to the glenohumeral joint surgeons divide infraspinatus and teres minor to reach to the posterior aspect and as this branch is close by and partly covered with fatty tissue careful attention should be given to this branch.

The eighth branches are muscular to teres minor, teres major, infraspinatus and subscapularis. The reason this study emphasizes these branches is not only to add to the literature, but as also because the subscapular or any of its branches are used as grafts: as the subscapular and the circumflex scapular arteries supply the glenohumeral joint capsule, glenoid labrum and surrounding structures from the anterosuperior aspect clockwise to the posterosuperior aspect, such arterial grafts could affect the blood supply of these structures leading to instability and dislocation of the glenohumeral joint as a secondary consequence.

Origin:

From the first part of the axillary artery:

The indirect origin of the circumflex scapular artery from the first part of the axillary artery via the subscapular artery shows variations. Saralaya et al. (2008) observed the first part giving a common subscapular trunk which then gave rise to the thoracoacromial, thoracodorsal, posterior circumflex humeral, lateral thoracic and circumflex scapular arteries. Goldman et al. (2012) reported a common trunk arising from the first part of the axillary artery which gave the thoracoacromial and subscapular arteries: the subscapular artery then gave the posterior circumflex humeral and lateral thoracic arteries following which it bifurcated into circumflex scapular and thoracodorsal arteries. Lee and Kim (2008) reported a bilateral variation of the subscapular artery arising from the first part of the axillary artery. On one side it branched into the lateral thoracic, thoracodorsal and a large posterior circumflex humeral, which later gave rise to the circumflex scapular artery, while on the other it gave the lateral thoracic, thoracodorsal and circumflex scapular arteries. Yotova and Novakov (2004) observed the first part of the axillary artery bifurcating into lateral and medial branches, with the lateral branch giving the lateral thoracic artery after which it continued into the arm as the brachial artery, while the medial branch descended and at the lower border of pectoralis minor gave (1) the subscapular artery which bifurcated into thoracodorsal and circumflex scapular arteries, the anterior circumflex humeral artery, the posterior circumflex humeral artery after which it continued into the arm as the profunda brachii. The present study did not observe any of these variations, with no origin either directly or indirectly from the first part of the axillary artery.

From the second part of the axillary artery:

An indirect origin of the circumflex scapular artery from the second part of the axillary artery via the subscapular artery has also shown variations. According to Verma et al. (2014) and Daimi et al. (2010) the circumflex scapular artery can arise from the second part of the axillary artery indirectly with the thoracodorsal artery via the subscapular artery. Durgun et al. (2002) partly agree reporting that the subscapular artery arose from the medial side of the second part of the axillary artery and gave the posterior circumflex humeral, thoracodorsal and circumflex scapular arteries. Arquez (2014) has reported the circumflex scapular artery arising from the second part of the axillary artery via a common trunk with the thoracodorsal, subscapular and posterior circumflex humeral arteries. Baral et al. (2009) partly agree stating that the circumflex scapular artery arose indirectly from the second part of the axillary artery via a common origin, but the accompanying branches were different. Chakravarthi et al. (2012) reported a different origin in which the second part of the axillary artery gave two main trunks, the first of which gave superior thoracic, clavicular and pectoral branches and the second lateral thoracic, posterior circumflex humeral, thoracodorsal, and subscapular branches, following which it continued as the circumflex scapular artery. Finally Olinger and Benninger (2010) reported that in 2.4% (n=2) the subscapular artery was absent with the lateral thoracic artery giving the circumflex scapular and thoracodorsal arteries. The current study does not support these variations arising indirectly from the second part of the axillary artery. Based on the findings of the current study it is concluded that: (1) since the majority of reports are case studies, the incidence of the circumflex scapular artery arising from the second part of the axillary artery cannot be determined; (2) the circumflex scapular artery arises indirectly from the second axillary artery in one of the three ways: either as one of two terminal branches of the subscapular artery, or from branches of the second part of the axillary artery, or from a common trunk with other branches, with the latter considered to be the most common; (3) all the case reports differ, but agree that the circumflex scapular arises indirectly from the second part of the axillary artery.

From the third part of the axillary artery:

Even when the circumflex scapular artery arises from the third part of the axillary artery it could be directly, via a common trunk or from one of the trunks. Samata Gaur et al. (2012) reported that the circumflex scapular artery arose directly from the third part of the axillary artery in 4% (n=1) of cases. Majumdar et al. (2013) and Khaki et al. (2011) agree reporting two cases in which the circumflex scapular artery arose directly from the third part of the axillary artery: in the first the subscapular artery was absent and in the second it arose from the second part of the axillary artery. The current study supports this concept in which and for the first time that the circumflex scapular artery can arise directly from the third part of the axillary artery, being observed in 1.4% (n=2) of specimens.

Others have reported the circumflex scapular artery arising from the third part of the axillary artery via a common trunk with both the anterior and posterior circumflex humeral, and subscapular arteries (Kachlik et al., 2011), or with the posterior circumflex humeral, lateral thoracic, subscapular and muscular branches (Agrawal et al., 2013), or with the lateral thoracic, posterior circumflex humeral and thoracodorsal arteries (Jain et al., 2013), or with the thoracodorsal and posterior circumflex humeral arteries (Salpek et al., 2007). The current study observed that the circumflex scapular artery can arise from the third part of the axillary artery as a common trunk with the posterior circumflex humeral artery, doing so in 2.12% (n=1) of specimens.

Division of the third part of the axillary artery into trunks, which was observed in 2% (n=2) by Sawant et al. (2012b), has shown different origins of the circumflex scapular artery. One study and two case reports have been published between 2006 and 2013, each of which emphasizes different origins. The circumflex scapular artery arose through the subscapular artery from the posterior division of the deep trunk of the third part of the axillary artery (Sawant et al., 2012b). Soubhagya et al. (2006) find that it arose via the subscapular artery from the medial of two trunks of the third part of the axillary artery. Bagoji et al. (2013) reported that it arose from one of three trunks named the subscapular trunk together with the thoracodorsal and posterior circumflex humeral arteries. The current study observed that the axillary artery divided into lateral and medial branches, of which the latter gave origin to the subscapular artery which then divided into the thoracodorsal and circumflex scapular arteries.

The circumflex scapular artery arose from the subscapular artery together with the thoracodorsal artery in 81.1% (n=49) and with additional muscular branches in 18.9% (n=11) (Jesus et al., 2008). The current study cannot give the incidence of this artery as it was not considered as part of the study; nevertheless, it has been observed and traced. It passed medially piercing the anterior aspect of subscapularis inside which it divides into several branches coursing medially and laterally to reach the anterior aspect of the glenohumeral joint supplying it.

Due to the lack of detailed information on the circumflex scapular artery this study adds that it arises from the subscapular artery in 97.9% (n=137), the profunda brachii in 0.7% (n=1) and directly from the third part of the axillary artery in 1.4% (n=2). Its site of origin being posterior (60.7%, n=85), posterolateral (27.9%, n=39), lateral (7.9%, n=11), posteromedial (2.1%, n=3) or medial (1.4%, n=2).

Anterior circumflex humeral artery:

Course and branches:

The anterior circumflex humeral artery runs laterally deep to both coracobrachialis and the short head of biceps brachii anterior to the surgical neck of the humerus to anastomose with the posterior circumflex humeral artery. At the intertubercular sulcus it gives an ascending branch supplying the shoulder joint and muscular branches to surrounding muscles (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946; Robinson, 1922). With respect to other branches of the anterior circumflex humeral artery information is lacking: the current study observed the same course but adds more anatomical detail concerning its branches. The first ascending branch, observed in 98.57% (n=138) of specimens, supplied the anterior and anteroinferior aspects of the anatomical neck of the humerus, the fibrous capsule, subscapularis and the anterior aspect of the surgical neck of the humerus. The second ascending branch, present in 94.42% (n=135) of specimens, supplied subscapularis, the anterior part of the fibrous capsule, the anterior and anterosuperior aspects of the anatomical neck, the lesser tuberosity and adjacent bone. The third ascending branch, which is also known as the ascending branch, is reported to arise consistently from the anterior circumflex humeral artery. In contrast, the current study observed that it was present in 98.57% (n=138) of specimens arising from the anterior circumflex humeral artery (97.10%, n=134), the brachial artery (2.2%, n=3) or the profunda brachii (0.7%, n=1). It ran superiorly into the bicipital groove on the posterior aspect of the tendon of long head of biceps to enter the fibrous capsule of the shoulder joint. It gave nutrient branches to the bicipital groove and anterior aspect of the greater tuberosity. The reason this study emphasizes these branches is because they supply the fibrous capsule, the surrounding structures and contribute indirectly to supplying the glenoid labrum through its attachment to the joint capsule and adjacent bone.

Origin:

The anterior circumflex humeral artery is smaller than the posterior circumflex humeral artery and arises from the lateral aspect of the third part of the axillary artery as a single branch or in common with the posterior circumflex humeral artery (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946; Robinson, 1922). The current study observed that the site of origin was either lateral (70.7%, n=99), posterolateral (17.9%, n=25), superior (5.7%, n=8), anterolateral (2.9%, n=4), posterosuperior (0.7%, n=1) posterior (0.7%, n=1) anterosuperior (0.7%, n=1) or anterior (0.7%, n=1). The diameter of the anterior circumflex humeral artery has been reported as being 2.8 mm (Yotova and Novakov, 2004); the current study found that the mean length and diameter in both genders were 61.76 mm and 2.14 mm respectively.

Classically the anterior circumflex humeral artery arises from the third part of the axillary artery as a single branch or in common with the posterior circumflex humeral artery (Moore et al., 2011; Ellis, 2006; Drake et al., 2005; Johnston and Whillis, 1946; Robinson, 1922). Huelke et al. (1959) stated that it arose from the third part of the axillary artery (80.3%, n=71) or as a common trunk with the posterior circumflex humeral artery (11.2%, n=10), the deep brachial artery (1.7%, n=2) or from other arteries (0.6%, n=1). According to Patnaik et al. (2000) the anterior circumflex humeral artery originates from the third part of the axillary artery in 96% (n=24) (being a single branch in 80% (n=29) and as a common origin with the posterior circumflex humeral artery in 16% (n=4) and from the profunda brachii and brachial artery in 2% (n=0.5) each. In an unusual case Saralaya et al. (2008) observed that the first part of the axillary artery gave a large collateral branch, the common subscapular trunk, which gave rise to the thoracoacromial, thoracodorsal, posterior circumflex humeral, lateral thoracic and circumflex scapular arteries, with the latter giving the anterior circumflex humeral artery. The anterior circumflex humeral artery originated from the lateral division in 3.37% (n=6) (Pandey et al., 2004), while others report that the deep brachial artery gives rise to the anterior circumflex humeral artery and the superficial brachial artery and two profunda brachii arteries running in the spiral groove (Bagoji et al., 2013). Double anterior circumflex humeral arteries have been observed in 2% (n=1) (Samata gaur et al., 2012), as well as being absent (Saeed et al., 2002). The current study partly agrees with Huelke et al. (1959) and Bagoji et al. (2013) reporting that the anterior circumflex humeral artery arising from the 3rd part of the axillary artery (87.1%, n=122), the posterior circumflex humeral artery (10.7%, n=15) and profunda brachii (2.1%, n=3). The anterior circumflex humeral artery arose from a common origin with the subscapular in 2.12% (n=1/47) and with the posterior circumflex humeral artery in 31.91% (n=15/47). Other variations such as double anterior circumflex humeral arteries or an origin from the first part of the axillary artery were not observed.

5.6.1.4. Common trunk origin:

From the first part of the axillary artery:

A common trunk has been reported with a number of variations. Goldman et al. (2012) observed a common trunk arising from the first part of the axillary artery which gave the thoracoacromial and subscapular arteries. The current study did not observe such a common trunk; however, it was observed to divide into two trunks, lateral and medial. The medial trunk descended inferiorly as the brachial artery, while the lateral trunk gave from its lateral side a common trunk during its course in the axilla, observed in 3.92% (n=2/51) of specimens. It then gave rise to the profunda brachii, subscapular and anterior and posterior circumflex humeral arteries.

From the second part of the axillary artery:

A number of studies (Arquez, 2014; Baral et al., 2009; Srimathi; 2011; Mehrdad and Sadeghi, 2007; Shantakumar and Mohandas Rao, 2012; Chitra and Anandhi, 2013) have reported a common trunk arising from the second part of the axillary artery, most of which have different branches. Arquez (2014) reported that it gave the thoracodorsal, circumflex scapular, subscapular and posterior circumflex humeral arteries while Baral et al. (2009) reported it gave the lateral thoracic, thoracodorsal, subscapular, circumflex scapular and posterior circumflex humeral arteries. According to Srimathi (2011) the common trunk gave rise to the thoracoacromial, lateral thoracic, subscapular and posterior circumflex humeral arteries, while Mehrdad and Sadeghi (2007) and Shantakumar and Mohandas Rao (2012) observed it bifurcating into subscapular and lateral thoracic arteries, and Chitra and Anandhi (2013) the subscapular, lateral thoracic and posterior circumflex humeral arteries. The current study notes that all of these studies were case reports: a common trunk was not observed arising from the second part of the axillary artery.

From the third part of the axillary artery:

Several studies have reported a common trunk arising from the third part of the axillary artery, with each giving different branches. Of these only three studies (Karambelkar et al., 2011; Astik and Dave, 2012; Samata Gaur et al., 2012) reported the incidence of the common trunk. Karambelkar et al. (2011) reported that the third part of the axillary artery gave a common trunk which then bifurcated into anterior and posterior circumflex humeral arteries in 20% (n=5), and a common trunk which bifurcated into posterior circumflex humeral and subscapular arteries in 8.33% (n=2). Astik and Dave (2012) reported that the common trunk gave the anterior and posterior circumflex humeral, subscapular and profunda brachii arteries in 12.5% (n=5) of specimens and gave rise to both anterior and posterior circumflex humeral arteries, as well as the profunda brachii, in 17.5% (n=7) of specimens. Samata Gaur et al. (2012) found that in 20% (n=5) a common trunk arose from the third part of the axillary artery giving rise to the subscapular and posterior circumflex scapular arteries.

According to Jain et al. (2013) the common trunk gives rise to the lateral thoracic, posterior circumflex humeral, thoracodorsal and circumflex scapular arteries, while Sarkar et al. (2014) stated it divided into only the posterior circumflex humeral, subscapular and lateral thoracic arteries. Agrawal et al. (2013) observed similar branches, these being the posterior circumflex humeral artery, lateral thoracic, subscapular, circumflex scapular and muscular branches. Earlier Rao et al. (2008) reported that the common trunk gave rise to the subscapular, anterior and posterior circumflex humeral, profunda brachii and ulnar collateral arteries. Kachlik et al. (2011)

reported four common trunks: the first gave the anterior and posterior circumflex humeral arteries; the second had two trunks one of which gave the superior thoracic and lateral thoracic arteries and the other the profunda brachii and both anterior and posterior circumflex humeral arteries; the third gave both anterior and posterior circumflex humeral arteries as well as the profunda brachii; and the fourth gave both anterior and posterior circumflex humeral, subscapular and circumflex scapular arteries. Salpek et al. (2007), Satyanarayana et al. (2012) and Pant et al. (2013) all report trifurcation of the common trunk, although the branches given differed. Salpek et al. (2007) reported the trifurcation being into the circumflex scapular, thoracodorsal and posterior circumflex humeral arteries, Satyanarayana et al. (2012) into the lateral thoracic and both anterior and posterior circumflex humeral arteries, while Pant et al. (2013) stated that it trifurcated into the thoracoacromial artery, the lateral thoracic artery and the subscapular arteries. The current study disagrees with Karambelkar et al. (2011), Astik and Dave (2012) and Samata Gaur et al. (2012) observing that the axillary artery branches have a common origin in 36.42% (n=51) of specimens, arising from the lateral trunk in 3.92% (n=2/51), the brachial artery in 3.92% (n=2/51) and the third part of the axillary artery in 92.16% (n=47/51). Furthermore, a common trunk arising from the third part of the axillary artery was seen in 92.16% shoulders (n=47/51), which gave rise to (i) both the anterior and posterior circumflex humeral arteries in 31.91% (n=15/47) from the posterolateral (12 shoulders), posteromedial (1 shoulder) and lateral (2 shoulders) aspects of the axillary artery; (ii) the posterior circumflex humeral and subscapular arteries in 57.44% (n=27/47) from the posterolateral (4 shoulders), posteromedial (19 shoulders) and medial (3 shoulders) aspects of the axillary artery; (iii) the posterior circumflex humeral and profunda brachii in 2.12% (n=1/47) from the lateral (1 shoulder) aspect of the axillary artery; (iv) the posterior circumflex humeral, subscapular and profunda brachii arteries in 4.25% (n=2/47) from the posterior (1 shoulder) and medial (1 shoulder) aspects of the axillary artery; (v) the posterior circumflex humeral and circumflex scapular arteries in 2.12% (n=1/47) from the posteromedial (1 shoulder) aspect of the axillary artery; and (vi) the anterior circumflex humeral and subscapular arteries in 2.12% (n=1/47) from the posterolateral (1 shoulder) aspect of the axillary artery. This study therefore adds to the literature that at the level of mid arm the brachial artery gives a common trunk from its lateral side in 3.92% (n=2/51) of specimens, which then bifurcates into the profunda brachii and posterior circumflex humeral arteries.

5.6.2. Suprascapular artery:

Course

As the suprascapular artery approaches the superior border of the scapula it classically courses superficial to the transverse scapular ligament separating it from the suprascapular nerve to enter the supraspinous fossa deep to supraspinatus. It then emerges from the spinoglenoid notch into the infraspinous fossa and runs inferiorly as far as the inferior angle of the scapula: it contributes to the anastomosis around the scapula (Gray, 1913; Smith et al., 1983; Hall-Craggs, 1990; Rogers, 1992; Snell, 1995; Monkhouse, 2001; Sinnatamby, 2006; Faiz and Moffat, 2006; Ellis, 2006; Moore et al., 2010). In contrast, a number of studies (Tubbs et al., 2003; Chen and Adds, 2011; Houtz and McCulloch, 2013; Pyrgakis et al., 2013; Mishra and Ajmani, 2003; Adibatti, 2010; Mahato, 2010 Shukla et al., 2012; Bagoji et al., 2012; Polguj et al., 2014; Yang et al., 2012) report that the suprascapular artery passes through the suprascapular notch, some of which report the suprascapular artery passing through the suprascapular notch. Mishra and Ajmani (2003) stated that it passed through the suprascapular notch in 1.6% (n=0.5) and Tubbs et al. (2003) in 2.5% (n=3). Polguj et al. (2014) classified the suprascapular artery, nerve and vein into four types depending on which structures pass deep or superficial to the transverse scapular ligament, while Yang et al. (2012) classified the suprascapular artery into three types, again depending on its relationship to the transverse scapular ligament: they also observed that in 48.9% (n=50) of specimens all types was observed bilaterally. The current study partly agrees with these findings observing that as the suprascapular artery approaches the superior border of the scapula it passes over the transverse scapular ligament in 83.6% (n=117) of specimens, while in 16.4% (n=23) it passes through the suprascapular notch.

Branches:

The suprascapular artery gives a number of branches: (1) those which share in the anastomosis around the scapula (Abrahams et al., 2011), (2) nutrient branches supplying both the scapula and clavicle (Gray, 1913), (3) an acromial branch which passes through trapezius to supply skin over the acromion as well as anastomosing with the acromial branch of the thoracoacromial artery (Gray, 1913), (4) muscular branches supplying subclavius and sternomastoid in addition to other muscles of the shoulder girdle (Lumley et al., 1995), (5) articular branches supplying the shoulder and acromioclavicular joints (Lumley et al., 1995; Gray, 1913), (6) a small subscapular branch which arises at the transverse scapular ligament and passes inferiorly into the subscapular fossa to ramify in subscapularis (Gray, 1913), and (7) a suprasternal branch which supplies skin over the superior part of the thorax (Gray, 1913). The current study agrees with these previous observations and organises and augments these branches as follows: (i) muscular to supraspinatus, infraspinatus and neighbouring muscles; (ii) a small subscapular branch given off as the artery passes over the transverse scapular ligament, which then descends into the subscapular fossa ramifying in subscapularis and giving periosteal branches to the subscapular fossa; (iii) articular to the acromioclavicular joint via two or three branches heading to the inferior aspect of the acromioclavicular joint as the suprascapular artery reaches the spinoglenoid notch; (iv) a small branch to the shoulder joint which was present in 85% (n=119) of specimens. This latter artery runs laterally posterior to the root of the coracoid process and parallel to the anterior aspect of the supraspinatus tendon passing through the distal aspect of supraspinatus and the superior aspect of the fibrous capsule to supply the superior region of the glenoid labrum and origin of the long head of biceps. It gave periosteal branches at the superior aspect of the glenoid neck and nutrient branches to the superior aspect of the glenoid neck and posterior part of the root of the coracoid process. Also in the spinoglenoid notch the suprascapular artery gave two or more branches which pierced the joint capsule from the posterosuperior and posterior aspects to supply the posterior aspect of the tendon of supraspinatus. The suprascapular artery also gave a nutrient artery to the scapula at the superior region of the lateral end of the root of the spine of the scapula, supraspinous fossa, infraspinous fossa and to the inferior aspect of the acromion. Finally, it gave periosteal branches in the supraspinous fossa which ran towards the glenoid neck with some passing to the infraspinous fossa.

5.6.3. Venous drainage their variations

The current study adds to the literature that the venae comitantes accompanying the ascending glenoid artery drain into the lateral vena comitante of the brachial artery, which later drains into the axillary vein. It receives muscular veins from subscapularis, biceps brachii, coracobrachialis and the rotator cuff tendons in addition to veins accompanying capsular arteries to the superior and anterosuperior aspect of the fibrous capsule, glenoid labrum and surrounding tissues.

Classically the axillary vein is formed by the union of the basilic and brachial veins at the lower border of teres major terminating at the outer border of the first rib by becoming the subclavian vein. It receives tributaries from the cephalic, subscapular, circumflex humeral, lateral thoracic and thoracoacromial veins (Palastanga et al., 2006, Moore et al., 2010): Yang et al. (2012) observed a duplicated axillary vein in 17.5% (n=7) of cases. Fujii et al. (2012) report a double axillary vein, while George et al. (2007) report a double axillary vein which joined to form a single axillary vein near its termination. An unusual variation was observed by Mahajan et al. (2012) in which the lateral thoracic artery pierced the axillary vein deep to pectoralis minor: this was confirmed histologically. Hadimani et al. (2013) also observed branches of the axillary artery perforating the axillary vein. The current study observed that in the majority of the shoulders the axillary vein was formed by the union of the basilic, brachial, subscapular and posterior circumflex humeral veins, and the medial vena comitante of the brachial artery and subscapular vein. Other veins such as the circumflex scapular and muscular veins occasionally share in its formation. A double axillary vein or artery piercing the axillary vein were not observed.

Yang et al. (2012) reported that the anterior circumflex humeral vein drained into the lateral brachial vein in 67.5% (n=27), while the posterior circumflex humeral vein drained either into the axillary (45%, n=18) or subscapular (42.5%, n=17) veins. The basilic vein joined with the medial venae comitantes of the brachial artery in 53.8% (n=14) and the brachial vein in 23.1% (n=6) before becoming the axillary vein. It received tributaries from the forearm and by the median cubital vein the intermediate cubital vein in 69.8% (n=19) of individuals, the intermediate basilic vein in 23.1% (n=6) and the intermediate basilic vein of the forearm in 3.8% (n=1) (Baptista-Silva et al., 2003; Palastanga et al., 2006). On the other hand, Yang et al. (2012) stated that the basilic vein was absent in 5% (n=2). Anaya-Ayala et al. (2011) classified the brachial-basilic vein anatomy into three types depending on where the basilica vein joined the brachial vein. Kaiser et al. (2010) reported a low union of the basilic vein and a single brachial vein. Classically the brachial veins are two deep venae comitantes accompanying the brachial artery which terminate by joining the basilic vein to form the axillary vein at the lower border of teres major (Hall-Craggs, 1990; Rogers, 1992; Snell, 1995; Drake et al., 2005; Palastanga et al., 2006; Moore et al., 2010). According to Yang et al. (2012) the brachial venae comitantes end separately with the basilic vein to form the axillary vein in 72.5% (n=29) or join together to form one common brachial vein in 27.5% (n=11), which then join either the basilic or the axillary vein. Santos et al. (2011) observed a common brachial vein in 73% (n=22) of specimens which drained directly into the axillary vein in 82% (n=18) and into the basilic vein in 18% (n=4). Kumar et al. (2012) also report a common brachial vein formed by union of the radial and ulnar veins which joined the basilic vein at the lower border of teres major to form the axillary vein. The current study adds to the literature the detailed anatomy of the veins that accompanying branches of the third part of the axillary artery. The posterior circumflex humeral vein was found as one vein in 72.86% (n=102) and as two veins in 27.14% (n=38): it received the anterior circumflex humeral vein (9.28%, n=13), muscular veins from deltoid, triceps, teres minor, subscapularis and adjacent muscles, veins from the head, anatomical and surgical necks of the humerus, as well as capsular and (occasionally) inferior glenoid veins. It also received an ascending vein from the profunda brachii vein (95.71%, n=113). The posterior circumflex humeral vein communicated with the anterior circumflex humeral vein in 93.57% (n=131) of specimens. In the case of two posterior circumflex humeral veins, during their course around the surgical neck of the humerus they communicated with each other in a variable manner draining directly into the axillary vein as a single vein (0.7%, n=1), or uniting with the subscapular, circumflex scapular, medial vena comitante of the brachial artery and basilic veins (28.78%, n=40), subscapular and basilic veins (6.5%, n=9), subscapular and circumflex scapular veins (5.7%, n=8) subscapular vein (3.6%, n=5), subscapular, lateral concomitant of brachial and basilic veins (2.16%, n=3), subscapular, circumflex scapular, lateral and medial vena comitantes of the brachial artery, profunda brachii and basilic veins (4.3%, n=6), lateral vena comitante and basilic veins (2.9%, n=5), basilic vein (5%, n=7), subscapular, medial vena comitante of the brachial artery and basilic veins (21.7%, n=30), circumflex scapular and medial vena comitante of the brachial artery (2.16%, n=3), subscapular, circumflex scapular and medial vena comitante (4.3%, n=6), subscapular, circumflex scapular and basilic veins (9.3%, n=13), subscapular, circumflex scapular, medial vena comitante of brachial artery and profunda brachii (2.16%, n=3), subscapular and medical vena concomitante of brachial artery (1.44%, n=2). The resulting vessel drained into the axillary vein (75%, n=105), lateral vena comitante of the brachial artery (0.7%, n=1), medial vena comitante of the brachial artery (9.3%, n=13), basilic vein (15%, n=21). (2) Two anterior circumflex humeral veins accompany the anterior circumflex humeral artery in 96.42% (n=135), or as a single vein in 2.9% (n=4) or three veins in 0.7% (n=1). It drained into the lateral vena comitante of the brachial artery (87.1%, n=122), the posterior circumflex humeral vein (10%, n=14) and the axillary vein (2.9%, n=4). It communicated with the posterior circumflex humeral veins in 93.57% (n=131) and received muscular veins from deltoid, teres major, latissimus dorsi, coracobrachialis, and biceps brachii, veins accompanying the ascending arteries (first, second and third) and nutrient veins from the anterior, anterolateral and lateral aspects of the humeral shaft. The circumflex scapular veins, each branch of the circumflex scapular artery was accompanied by two vena comitante (sometimes one), receiving veins from the infraspinous and supraspinous fossae, supraspinatus, teres minor and major, the long head of triceps, the inferior, posteroinferior and posterior aspects capsule veins and surrounding tissues. The circumflex scapular veins drained directly into the subscapular vein accompanied by the thoracodorsal vein. The subscapular vein received the thoracodorsal and circumflex scapular veins. It did not drain directly into the axillary vein, but united with other veins to form a single vein which drained into the axillary vein. One reason why this study emphasizes the detailed anatomy of these veins, besides adding to the literature, is that surgeons should be aware of such variations in cases of venous ligation or any other relevant operation.

5.7. Histology of the glenoid labrum and its innervation

5.7.1. Histology of the glenoid labrum:

The glenoid labrum is the cause of some confusion as to its constitution, which has been observed to be diverse. According to Schafer and Thane (1892), Robinson (1922) and Howell and Galiant (1989) it is as a fibrous ring or fibrous band. In contrast, Snell (1995), Carey et al. (2000), Drake et al. (2005), Palastanga et al. (2006), Sinnatamby (2006) and Moore et al. (2010) state that it is a cartilaginous structure. However, Nazir et al. (2014) report that during week 10 of gestation the glenoid labrum is fibrocellular rather than fibrocartilaginous with collagen fibres; furthermore it was vascular with more capillaries growing in the free margin by week 12½. In contrast, Moseley and Overgaard (1962), Cooper et al. (1992), Pfahler et al. (2003) and Bain et al. (2012) are of the opinion that the glenoid labrum is composed of dense fibrous tissue with a narrow fibrocartilaginous zone between the articular hyaline surface and glenoid labrum. A crevice (cleft or fissure) has been observed to lie in the transitional zone between the fibrous glenoid labrum and the hyaline cartilage in 36.36% of the shoulders, being characterized by hypercellularity and collagen fibre orientation (Cooper et al., 1992); however, its function is still unknown. Pfahler et al. (2003) classified shoulders according to age: group I, less than 40 years; group II, between 40 - 60 years; group III, more than 60 years, with changes in the articular surface, transitional zone, superior and anterosuperior aspects of the glenoid labrum being identified even in group I. Cellularity and vascularity of the labrum and the transitional zone increased with age, being more in group III. Ockert et al. (2012) confirmed that the glenoid labrum has a circumferentially avascular fibrocartilaginous zone constituting up to one third of the glenoid labrum in cross section: the rest being dense fibrous tissue. Arai et al. (2012) report that the composition of the superior glenoid labrum is collagen fibres, which run circumferentially along with some elastic fibres. Using electron microscopy Nishida et al. (1996) reported that the glenoid labrum consisted of three layers of collagen: the superficial layer was a thin reticular fibrillar network, the second a stratified layer while the third layer consisted of densely arranged bundles of fine fibrils which ran parallel to each other but oblique to the glenoid rim. The function of the first and second layers is to act as a bumper counteracting humeral head impaction, while the third layer stabilizes the glenohumeral joint through a cushion effect. Hill et al. (2008) reported three glenoid labrum zones: the first is a superficial mesh of multidirectional fine fibrils believed to decrease the surface friction of the joint through lubrication; the second is a loose orientation of fibres characterized by its vascularity and noted to be most common in the anterosuperior region compared to other regions. The main action of this zone is hypothesized to act in a viscoelastic manner by expressing fluid during loading and recovery in unloading allowing the glenoid labrum to counteract excessive compression applied on any point, besides, it might tether the underlying layer; and the third is the central core which is considered to be the largest, consisting of large dense fibre bundles circumferentially oriented and avascular. This latter layer is thought to aid in transferring tensile forces from compression and translation at the glenohumeral joint which in turn indirectly reduces the contact stress on the underlying hyaline articular surface. Using light microscopy the current study agrees with Ockert et al. (2012) stating that the glenoid labrum is fibrocartilaginous becoming more fibrous in the periphery. However, a crevice in the transitional zone between the fibrous glenoid labrum and the hyaline cartilage could not be observed. It supports Hill et al. (2008) in that the whole glenoid labrum is vascular with the anterosuperior aspect of the glenoid labrum having a rich blood supply.

Mode of attachment, size and composition:

According to Hill et al. (2008) the glenoid labrum is attached to the underlying glenoid bone by vertical and oblique interweaving fibres with associated Sharpey's fibres anchoring onto the superficial bony surface of the glenoid. Whereas the attachment to the underlying hyaline cartilage is by finger-like processes via foramen in the superficial aspect of the hyaline cartilage in association with Sharpey's fibres: it was noted that the region between the glenoid labrum and the hyaline cartilage was cellular suggesting a transitional zone. The interdigitating anchoring fibres and Sharpey's fibres attach to the underlying glenoid bone and cartilage in different orientations supporting the idea that the glenoid labrum is subjected to various multidirectional forces. Bain et al. (2012) agree with Hill et al. (2008) stating that the glenoid labrum interfaces with the underlying bone through uncalcified fibrocartilage then calcified fibrocartilage integrating Sharpey's fibres to bone. The collagen fibres of the glenoid labrum at the labrum-articular cartilage interface were not very dense between 11 and 4 o'clock and were associated with loose or incomplete attachment of the glenolabral junction, however a complete attachment between the glenoid labrum and the underlying articular cartilage between 5 and 11 o'clock was observed. The glenoid labrum region between 10 and 12 o'clock was attached to the apex of the glenoid rim, while in the other regions of the clock face the articular cartilage did not extend to the glenoid edge because the glenoid labrum had a bony foundation and was covered by the glenoid edge. The current study agrees observing that the glenoid labrum attached to the underlying articular surface centrally and was anchored to the underlying glenoid bone peripherally, reaching to bone trabeculae in some regions. Grossly, the superior half of the glenoid labrum (mainly from 11 to 2 o'clock) was incompletely attached to the underlying articular surface and glenoid bone.

Prodromos et al. (1990) reported the consistency of the glenoid labrum to range from rubbery to firm. Shoulders of individuals in their fifth decade at the time of death had a glenoid labrum that was thin and virtually absent. The glenoid labrum was sparsely vascularized without any configurative pattern of distribution: the vascularity was observed to decrease with age. Lapner et al. (2010) observed that the vascular channels proliferating inside the glenoid labrum and glenoid bone increased with gestational age. The current study observed that the consistency of the superior half of the glenoid labrum was rubbery in 97.86% (n=137) and firm in 2.14% (n=3) of specimens, whereas the entire inferior half was firm. Assuming that the shape and size of the glenoid labrum is linked to its consistency the superior half of the glenoid labrum was triangular and larger giving it the rubbery appearance whilst the inferior half was rounded and smaller in size making it firm.

5.7.2. Innervation of the glenoid labrum:

Neural receptors of the glenohumeral joint have rarely been observed: the first report was by Vangsness et al. (1995) using a modified gold chloride stain. In the fibrous capsule, there were slow adapting Ruffini end organs, rapidly adapting Pacinian corpuscles as well as free nerve endings in the glenohumeral, coracoclavicular and coracoacromial ligaments. Free nerve endings were noted in the present study, but could not be confirmed, in the peripheral part of the glenoid labrum as well as the subacromial bursae. The number of neural receptors was not quantified. Mechanoreceptors could not be detected in the glenoid labrum. However, Guanche et al. (1999), using the same stain as Vangsness et al. (1995), reported four neural receptors, these being Golgi, Ruffini and Pacini corpuscles as well as free nerve endings in 45% of the superior glenohumeral ligament, 42% of the middle glenohumeral ligament, 48% of the inferior glenohumeral ligaments and 47.5% of the fibrous capsule. Only free nerve ending were revealed in the long head of biceps tendon and the attached part of the superior glenoid labrum. According to Machner et al. (1998) proprioceptive sensations of the glenohumeral joint were deficient in posttraumatic anterior glenohumeral instability: a significant improvement in joint proprioception was achieved 18 months following arthroscopic labral repair which raises the question of whether the sensory nerve fibres of the glenoid labrum play a role in proprioception of the glenohumeral joint. The current study augments, using silver nitrate stain, the findings of Vangsness et al. (1995), Guanche et al. (1999) and Machner et al. (1998) and for the first time, using immunohistochemistry, confirms that there are free sensory nerve fibres in the glenoid labrum. No mechanoreceptors were observed. This finding emphasizes that tears of the glenoid labrum could induce pain; furthermore, if the glenoid labrum is enriched with sensory fibres it could play a role in glenohumeral joint proprioception.

5.8. Glenoid labrum lesions and their managements

The current study concludes that due to the complex pathologies affecting to the glenoid labrum researchers are encouraged to investigate their aetiology and subsequently classify them into a number of types and subtypes.

5.8.1. SLAP lesions:

Due to high incidence of their occurrence and the importance of SLAP lesions in affecting glenohumeral joint stability, several studies were conducted and a ten types of classification (Powell et al., 2004) based on tear size, has been put forward. Despite this, the biomechanical aetiology of SLAP lesions is still unexplained, however several theories have been considered. Synder et al. (1995), Clavert et al. (2004) and Sanders et al. (2006) are of the opinion that direct trauma of the humeral head against the superior aspect of the glenoid labrum leads to SLAP lesions. Andrew et al. (1985), Yeh et al. (2005), Dewan et al. (2012) and Pradhan et al. (2001) state that repetitive overhead activities are postulated to induce SLAP lesions whereas Pfahler et al. (2003) considered them to be due to aging. In contrast, Shepard et al. (2004) reported that a SLAP Type II lesion can be achieved with a posterior-directed load on the long head of biceps tendon. Others (Mihata et al., 2009) believe that a decrease in the strength of subscapularis leads to an increase in both external rotation and contact pressure at the glenohumeral joint causing a SLAP Type II associated with a rotator cuff tear.

SLAP lesions are associated with anterosuperior impingement of the glenohumeral joint (Gerber and Sebesta, 2000). Few authors have observed an association between SLAP lesions and Buford complex (Bents and Skeete, 2005; Brue et al., 2008). Tirman et al. (1994) noted that SLAP lesions were associated with a cystic-appearing mass, while other suggest that variation of the glenoid labrum could be the confounding factor of SLAP lesions as they were significantly higher in shoulders with sublabral foramen and Buford complex (Ilahi et al., 2002). The current study observed different types of SLAP lesion, but was reluctant to take them into consideration because, firstly it is beyond the goal of the current study, and secondly it is possible that these lesions occurred postmortem due to manipulation. Based on the above studies, the current study tends to agree that several factors could cause SLAP lesions including direct trauma, the aging process and repetitive minor trauma.

Several techniques were reported for SLAP lesion management. According to Enad and Kurtz (2007), Maier et al. (2013), Kanatli et al. (2011) and Yung et al. (2008) arthroscopic repair by suture anchors is effective and gives good outcome, with Kim et al. (2011) and Ok et al. (2012) stating that a double row repair is effective in the restoration of stability. Kartus et al. (2004) used a Cork-Screw anchor procedure which showed encouraging results. Kim et al. (2012) reported that SLAP and long head of biceps tenotomy and rotator cuff repair was giving better results. In contrast, Abbot and Busconi (2009) declared that the treatment choice for SLAP type II lesions associated with rotator cuff tears was arthroscopic repair of the rotator cuff tear with subacromial decompression combined with debridement of the glenoid labrum. In contrast, Yoneda et al. (1991) mentioned that the treatment of SLAP type II lesion by debridement of the detached glenoid labrum and abrasion of the glenoid rim until it bleeds and then fixed by staples provided an excellent or good outcome in 80% (n=8) of patients. Based on these studies, the current study notes, despite the different types of surgical techniques in several types of SLAP lesions (Table 2.10.1), the majority of the results are excellent leading to the conclusion that the glenoid labrum has rich blood supply enabling it to reattach again.

5.8.2. Bankart lesion:

Does anterior dislocation of the glenohumeral joint cause Bankart lesion or vice versa? If the lesion is due to anterior dislocation does it cause the dislocation?

Ito et al. (2005) consider a Bankart lesion an essential finding in traumatic recurrent anterior dislocation leading to anterior glenohumeral joint instability. Widjaja et al. (2006) stated that Bankart lesion frequently occur after anterior glenohumeral joint dislocation being 67% (n=10) in primary dislocation and 73% (n=11) in recurrent dislocation. According to Mizuno et al. (2005) the incidence of anterior glenohumeral dislocation due to Bankart lesions is 92.1% (n=279), whereas Sugimoto (2004) found a Bankart lesion in 52% of cases (n=46). Song et al. (2006) noted that Bankart lesion was observed in 92% (n=23) of patients with recurrent anterior dislocation of the glenohumeral joint. With regards to Perthes lesion, Wischer et al. (2002) and Song et al. (2006) have reported it with an incidence of 12% (n=9) to 16% (n=4). Based on these studies, the current study notes that Bankart lesions and Hill-Sachs defect are not only associated with either primary or recurrent glenohumeral dislocation, but can also cause anterior dislocation. However, Sekiya et al. (2012) declare that 25% of isolated Hill-Sachs defects increase glenohumeral joint translation significantly, but that it is not responsible for recurrent dislocation of the joint.

According to Lai et al. (2006) open Bankart repair with suture anchors associated with the capsular shift procedure was more effective. Kamath et al. (2013) reported that two double loaded suture anchors were giving better results. Kim et al. (2009b) confirmed that arthroscopic three-point double row reconstruction of Bankart lesions provided stable fixation. Millett et al. (2013) reported that even in arthroscopic bony Bankart Bridge to treat Bankart lesions with an average glenoid bone loss of 29% they observed that successful stability was achieved in 93% (n=14). Based on the literature the current study emphasizes that although there are different techniques (Table 2.10.2), either open or arthroscopic, in the management of Bankart lesions the majority of results are perfect, again suggesting that the anterior and anteroinferior glenoid labrum has a rich blood supply enhancing the repair.

5.8.3. Posterior glenoid labrum tear (reverse Bankart lesion) and circumferential tear:

Mair et al. (1998) and Escobedo et al. (2007) suggest that repeated exposure to trauma can lead to glenoid labrum tear which was observed, including the posterior type, in 96% (n=26) of shoulders in footballers compared to 22% (n=31) in non-football players. However, Fitzcharles and Charles (2012) are of the opinion that a posterior glenoid labrum tear with detachment and a loose body due to direct trauma to the shoulder was always associated with posterior glenohumeral joint instability.

Furthermore, re-attachment of the posterior glenoid labrum tear has been undertaken with the individual back to playing golf 7 months later (Faustin et al., 2007). With regards to the circumferential type of tear, only three cases have been reported (Dikens et al., 2012). The current study notes that: (i) there are few reports on circumferential and posterior glenoid labrum tears, (ii) the majority of studies report that trauma was the cause of this type of tear, and (iii) a complete re-attachment took place not only in the posterior type but also in the circumferential type with an average follow-up 6 to 7 months, again emphasizing that the glenoid labrum has a rich blood supply.

It can be asked why the current study has considered glenoid labrum lesions, diagnosis, treatment and its outcome, as well as including it in the discussion and its relationship to the main aim of this study. Firstly, the current study has confirmed through gross anatomy and histology that the glenoid labrum has a rich vasculature. Secondly, as the current study was on cadavers, one limitation in determining if this blood supply is sufficient for healing any kind of glenoid labrum tear has to consider different types of lesions, their management and outcome. Thirdly, the current study emphasizes that despite the high incidence of glenoid labrum lesions, including all types, and its important function in stability of the glenohumeral joint, no anatomy textbooks mention its blood supply. Furthermore, few anatomical and histological studies have been undertaken.

Chapter 6: Conclusion

Improvements in diagnostic imaging and shoulder arthroscopy help surgeons to diagnose and treat shoulder joint pathology, particularly trauma involving the glenoid labrum. An understanding of the blood supply to the glenoid labrum could change surgical treatment plans from arthroscopic debridement to repair. This understanding could lead to faster healing with fewer complications, especially with recurrent dislocation: a better prognosis can therefore be accomplished. A knowledge of the blood supply and its variations, together with variations in glenoid labrum anatomy, innervation and histology, may enable clinical associations with intra-articular abnormalities to be evaluated. An appreciation of these variations could contribute to a better understanding of the biomechanics of the shoulder joint.

Grossly, the superior half of the glenoid labrum is incompletely attached to the underlying articular surface and glenoid bone. Generally, the fibrous capsule is attached to the lateral surface of the glenoid labrum and glenoid bone, whereas occasionally the fibrous capsule splits to engulf the glenoid labrum. The consistency of the superior half of the glenoid labrum was mainly rubbery, whereas the entire inferior half was firm: assuming that the shape and size of the glenoid labrum is linked to its consistency the superior half of the glenoid labrum is triangular and larger giving it a rubbery appearance whilst the inferior half is rounded and smaller in size making it firm.

The thickest part of the glenoid labrum was at 12 o'clock and thinnest at 3 o'clock: there was a difference between males and females, being thicker in males in all the regions. The difference was significant at 12 o'clock, 6 o'clock and 9 o'clock. The deepest part of the glenoid labrum was at 12 o'clock and the shallowest region at 3 o'clock. There was a difference in depth between males and females, being deeper in males in all regions: the differences were significant at 12 o'clock and 6 o'clock. Taken together the anterior aspect of the glenoid labrum is the thinnest and shallowest region which could be related to the high incidence of the anterior glenohumeral dislocation.

A sublabral foramen was found in 28.57% (n=40) being slightly more so in males and also more common on the right than the left side in both genders. A Buford complex was seen in 1.42% (n=2) of specimens. With regards to a sublabral recess, type I was the most commonly seen followed by type II.

Regarding the attachment of the long head of biceps to the glenoid labrum, types I and II were the most common.

The shape of the glenoid fossa was pear-shaped in 70% and oval in 30%, suggesting that comma and pear-shaped glenoid fossae are more or less the same with the first having a more severe glenoid notch. A glenoid notch was presented in all specimens, with type III being the most common followed by type II. The overall mean length, width and length at maximum width of the glenoid fossa was significantly greater in males than females. That the mean length at the maximum width in males and females was smaller than half the mean length of the whole glenoid emphasizes the fact that the glenoid fossa is pear-shaped and not rounded. A bare spot was observed in 80.71% (n=113) of shoulders, being more common in males than females and significantly longer and wider in males. The overall mean length and diameter in both genders was 7.16 mm and 6.19 mm, giving it a rounded to oval shape.

The superior glenohumeral ligament was observed in all specimens arising as a single band from the anterosuperior aspect of the glenoid labrum between the long head of the biceps attachment and the middle glenohumeral ligament. The middle glenohumeral ligament was seen in 98.57% (n=138) having a mean thickness greater in males than females: the difference was significant. The inferior glenohumeral ligament anterior band was found in all specimens arising from the anteroinferior aspect of the glenoid labrum between 3 and 5 o'clock. Its mean thickness was greater in males than females: the difference was significant. The inferior glenohumeral ligament posterior band was present in 79.28% (n=111) arising from the posteroinferior aspect of the glenoid labrum between 7 and 9 o'clock. Again its mean thickness was greater in males than females: the difference being significant.

The long head of triceps was observed to have an extended attachment. In addition to its origin from the infraglenoid tubercle, with some contribution from the posteroinferior and inferior aspects of the glenohumeral fibrous capsule, there was a fibrous slip to both sides of the superior part of the lateral border of the scapula. The overall mean width, superior and inferior thickness were significantly greater in males than females. Knowledge of the anatomical variations of the long head of triceps could be important because it has a contribution to the posteroinferior aspect of the fibrous capsule of the shoulder joint and could be injured during associated surgery. As a consequence there could also be a decrease in the posteroinferior support of the fibrous capsule to the head of humerus which could potentially lead to instability of the glenohumeral joint.

A tuberculohumeral ligament was seen in 54.83% (n=34/62) of specimens extending from the inferior glenoid tubercle to the posterior aspect of the surgical neck of the humerus: only the length between males and females was significantly different. These findings should encourage future investigations to evaluate the histological composition of this ligament.

In summary, the blood supply of the glenoid labrum by regions is as follows: the superior and anterosuperior regions receive their arterial supply from the ascending glenoid and suprascapular arteries as well as muscular branches from subscapularis and supraspinatus; the anteroinferior and inferior regions receive their blood supply from periosteal branches of the circumflex scapular and inferior glenoid arteries, with the latter being a branch from either the posterior circumflex humeral, circumflex scapular or subscapular artery, as well as muscular branches from triceps and subscapularis. The posteroinferior and posterosuperior regions receive their arterial supply from periosteal branches from the suprascapular artery, muscular branches from teres minor and infraspinatus and occasionally an ascending branch from the circumflex scapular artery giving periosteal and direct branches to these regions as well as branches from the anterior and posterior circumflex humeral arteries which pierce the capsule anterosuperiorly, anteroinferiorly, inferiorly and posteroinferiorly supplying the anatomical neck, some of which also supply the labrum through the fibrous capsule. In addition, the glenoid labrum receives a blood supply from the underlying bone (Figure 4.7.5).

Histologically, the glenoid labrum is fibrocartilaginous becoming more fibrous in its periphery. The whole of the glenoid labrum is vascular with the anterosuperior aspect having a rich blood supply. The glenoid labrum attaches to the underlying articular surface centrally and is anchored to the underlying glenoid bone peripherally, reaching to bony trabeculae in some regions. Several blood vessels were observed coming from the fibrous capsule supplying the glenoid labrum. Occasionally, the glenoid labrum reaches bony trabeculae through the periosteal layer, therefore providing another source of its blood supply.

By using a silver nitrate stain and immunohistochemistry it was observed that there are free sensory nerve fibres in the glenoid labrum. No mechanoreceptors could be observed. This could explain why tears of the glenoid labrum induce pain; furthermore, if the glenoid labrum is rich with sensory fibres it could have a role in glenohumeral joint proprioception.

The aims and objectives of the current study have been accomplished as follows:

1. Identification of the blood supply of the glenoid labrum.
2. The attachment of the glenoid labrum to the glenoid fossa has been determined.
3. The shape and dimension of the glenoid fossa have been assessed.
4. The shape, thickness and depth of the glenoid labrum have also been assessed.
5. The modes of attachment of the long head of biceps brachii as well as triceps have been investigated.
6. The attachment of the fibrous capsule to the glenoid labrum has been revealed.
7. The attachment of the glenohumeral ligament to the glenoid labrum has been evaluated.
8. The nerve fibres of the glenoid labrum have been identified.

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Appendix 1

Table 1: Variations of the lateral thoracic artery. 1st AA: first part of the axillary artery, 3rd AA: third part of the axillary artery, Subs: subscapular artery, ST: superior thoracic artery, TD: thoracodorsal artery, PCHA: posterior circumflex humeral artery, CR: case report.

Lateral thoracic artery	Arises from (%)				Gives off (%)			
Studies	Subs	1stAA	3rdAA	AB	ST	Subs	TD	PCHA
Huelke et al. (1959)		10.7	1.7		CR			
Daimi et al. (2010)		CR						
Farhan and Selman (2010)	5					7		2
Saralaya et al. (2008)		CR						
Goldman et al. (2012)	CR							
Goldman (2008)	CR							
Lee and Kim (2008)	CR							
Yotova and Novakov (2004)		CR						
Durgun et al. (2002)		CR						
Jain et al. (2013)			CR					
Agrawal et al. (2013)			CR					
Sarkar et al. (2014)			CR					
Olinger and Benninger (2010)	4.2					5.4	7.2	1.2
Majumdar et al. (2013)	CR			CR				
Rao et al. (2008)			CR					
Pant et al. (2013)			CR					
Astik and Dave (2012)	22.5							

Table 2: Variations of the superior thoracic artery. 1st AA: first part of the axillary artery, 2nd AA: second part of the axillary artery, TA: thoracoacromial artery, LT: lateral thoracic artery. Subc: subclavian artery, CR: case report.

Superior thoracic artery	Arises from (%)					
Studies	Subc	1st AA	2nd AA	TA	LT	absent
Huelke et al. (1959)	5.6	86.6	2.2	1.7	1.7	2.2
Chakravarthi et al. (2012)			CR			
Troupis et al. (2014)			CR			

Table 3: Variations of the thoracoacromial artery. 1st AA: first part of the axillary artery, 3rd AA: third part of the axillary artery, ST: superior thoracic artery. DA and CP: deltoacromial and clavipectoral branches, CR: case report.

Thoracoacromial artery	Arises from (%)			Gives off (%)	
Studies	1st AA	3rd AA	absent	ST	DA and CP
Huelke et al. (1959)	29.8			1.7	
Astik and Dave, (2012)			12.5		7.5
Daimi et al. (2010)	CR				
Saralaya et al. (2008)	CR				
Goldman et al. (2012)	CR				
Goldman (2008)	CR				
Chitra and Anandhi (2013)			CR		
Pant et al. (2013)		CR			
Troupis et al. (2014)		CR			

Table 4: Variations of the subscapular artery. 1st AA: first part of the axillary artery, 2nd AA: second part of the axillary artery, 3rd AA: third part of the axillary artery, LT: lateral thoracic artery, TD: thoracodorsal artery, DB: deep brachial artery, AB: absent, PCHA: posterior circumflex humeral artery, CR: case report.

Subscapular artery	Arises from (%)							Gives off (%)	
Studies	LT	TD	1stAA	2ndAA	3rdAA	DB	AB	LT	PCHA
Huelke et al. (1959)		0.6							
Astik and Dave (2012)								CR	
Samata gaur et al. (2012)				4					
Daimi et al. (2010)				CR					
Arquez (2014)				CR					
Chakravarthi et al. (2012)				CR					
Baral et al. (2009)				CR					
Farhan and Selman (2010)	7							5	11
Saralaya et al. (2008)			CR						
Goldman et al. (2012)			CR						
Goldman (2008)			CR						
Lee and Kim (2008)			CR						
Durgun et al. (2002)			CR	CR					
Srimathi (2011)				CR					
Mehrdad and Sadeghi (2007)				CR					
Chitra and Anandhi (2013)				CR					
Verma et al. (2014)				CR					
Olinger and Benninger (2010)	5.4						2.4	4.2	
Karambelkar et al. (2011)				6.66					
Hartley and Marquez (2012)					56				
Khaki et al. (2011)							CR		
Majumdar et al. (2013)				CR				CR	CR
Patnaik et al. (2000)			16		58		4		
Jesus et al. (2008)					82.6				6.53
Cavdar et al. (2000)						CR			
Salpek et al.(2007)							CR		
De Paula et al. (2013)						CR			
Hattori et al. (2013)					33.9				

Table 5: Variations of the posterior circumflex humeral artery. 1st AA: first part of the axillary artery, 2nd AA: second part of the axillary artery, 3rd AA: third part of the axillary artery, LT: lateral thoracic artery, DB: deep brachial artery, CSA: circumflex scapular artery, CR: case report.

Posterior circumflex humeral	Arises from (%)								
Studies	LT	Subs	1stAA	2ndAA	3rdAA	BA	CSA	DB	others
Farhan and Selman (2010)	2	11				9			
Saralaya et al. (2008)			CR						
Goldman (2008)		CR							
Lee and Kim (2008)			CR						
Srimathi (2011)				CR					
Chitra and Anandhi (2013)				CR					
Durgun et al. (2002)		CR							
Swamy et al. (2013)				CR					
Olinger and Benninger (2010)	1.2				77.1	8.4	12		
Hartley and Marquez (2012)		6			56				
Majumdar et al. (2013)		CR							
Patnaik et al. (2000)					96				
Hattori et al. (2013)					33.9				
Garry and Marquez (2008)		6.53							
Huelke et al. (1959)		15.2			67.5			2.8	2.2

Table 6: Variations of the anterior circumflex humeral artery. 1st AA: first part of the axillary artery, 2nd AA: second part of the axillary artery, 3rd AA: third part of the axillary artery, BA: brachial artery, DB: deep brachial artery, CR: case report.

Anterior circumflex humeral	Arises from (%)					
Studies	2nd AA	3rdAA	DB	BA	Others	Absent
Huelke et al. (1959)		80.3	1.7		0.65	
Saeed et al. (2002)	CR					CR
Bhat et al. (2008)	CR					
Patnaik et al. (2000)		96	2	2		
Bagoji et al. (2013)				CR		

Table 7: Variation of the common trunk origin from the 1st and 2nd parts of the axillary artery. ST: superior thoracic artery, CA: coracoacromial artery, PB: profunda brachii, LT: lateral thoracic artery, PCHA: posterior circumflex humeral artery, TD: thoracodorsal artery, SUB: subscapular artery, CSA: circumflex scapular artery, TA: thoracoacromial artery, ACHA: anterior circumflex humeral artery.

Studies	Site	ST, CA & PB	LT, PCHA, TD, SUB & CSA	TA & SUBS	LT, PCHA, TA & SUB	Gives all except ACHA & ST	SUB&LT	SUB, LT &PCHA	Superficial and deep	LT&SUB	TD, CSA, PCHA, SUB
Saralaya et al. (2008)	1AA		CR								
Goldman et al. (2012)	1AA			CR							
Baral et al. (2009)	2AA		CR								
Srimathi (2011)	2AA				CR						
Arquez (2014)	2AA										CR
Chakravarthi et al. (2012)	2AA	CR	CR								
Bhat et al. (2008)	2AA					CR					
Mehrdad and Sadeghi (2007)	2AA						CR				
Chitra and Anandhi (2013)	2AA							CR			
Yohannan and Ravindran (2013)	2AA								CR		
Shantakumar and Mohandas Rao (2012)	2AA									CR	
Pandey et al. (2004)	2AA								CR		

Table 8 (A,B): Variation of the common trunk origin from the 3rd part of the axillary artery, PB: profunda brachii, LT: lateral thoracic artery, PCHA: posterior circumflex humeral artery, TD: thoracodorsal artery, SUB: subscapular artery, CSA: circumflex scapular artery, ACHA: anterior circumflex humeral artery. DB: deep brachial artery.

A

Studies	ACHA &PCHA	PCHA & SUB	ACHA & DB	ACHA, OTHERS	ACHA, PCHA, SUB & PB	ACHA, PCHA & PB
Huelke et al. (1959)	11.2		1.7	0.6		
Astik and Dave (2012)					12.5	17.5
Samata Gaur et al. (2012)		20				
Jurjus et al. (1999)	CR					
Karambelkar et al. (2011)	20	8.33				
Kachlik et al. (2011)	CR					CR
Patnaik et al. (2000)		18				

B

Studies	PCHA, LT, SUBS, CSA	PCHA,LT,TD, CSA	PCHA,SUBS,LT	Superficial & Deep
Jain et al. (2013)		CR		
Sarkar et al. (2014)			CR	
Agrawal et al. (2013)	CR			
Troupis et al. (2014)				CR

Appendix 2

Table 1: Tissue processing protocol

Agent	Time
Ethanol 70%	15 minutes
Ethanol 85%	15 minutes
Ethanol 90%	25 minutes
Ethanol 95%	25 minutes
Ethanol 100%	15 minutes
Ethanol 100%	15 minutes
Histoclear	15 minutes
Histoclear	30 minutes
Wax	30 minutes
Wax (always finished in wax)	30 minutes

Table 2: Procedure for staining sections with haematoxylin and eosin.

Agent	Time
Histoclear 1	3 minutes
Histoclear 2	3 minutes
100% Ethanol 1	3 minutes
100% Ethanol 2	3 minutes
70% Ethanol	3 minutes
Tap water	3 minutes
Mayer haematoxylin	5 minutes
Tap water	3 minutes
Scotts tap water	30 seconds
Tap water	2 minutes
Eosin	5 minutes
Tap water	10 seconds
95% ethanol	15 seconds
100% ethanol 3	2 minutes
100% ethanol 4	2 minutes
100% ethanol 5	2 minutes
Histoclear 3	3 minutes
Histoclear 4	3 minutes
Drain slide briefly and mount coverslip using Permount or Styrolite	Leave it overnight to dry in the hood

Silver nitrate protocol

Gless-Marsland modification

The tissue must be fixed in formalin-saline or natural buffered formalin solution and the paraffin sections should be cut at 6–8 micrometres thickness.

Solutions and reagents:

1. 20% silver nitrate stock solution: to prepare dissolve 10 gm silver nitrate in 50 ml distilled water.

2. 10% formalin solution and must be alkaline: to prepare add 10 ml 37-40% formaldehyde to 90 ml distilled water.

3. Glees's silver solution: add 30 ml from the 20% silver nitrate stock solution to 20ml alcohol then add strong ammonia (0.88) (must be done in fume cupboard) drop by drop with a constant agitation until re-dissolves then add 5 more drops.

4. 5% aqueous sodium thiosulphate

Method:

1. Rehydrate and clear sections through ethanol and Histoclear then place the sections in distilled water.

2. Silver nitrate solution at 37°C for 25-30 minutes.

3. Rinse in distilled water.

4. Rinse twice and quickly (10 seconds) with 10% formalin solution.

5. Wash off the formalin with Glees's silver solution for 30 seconds.

6. Pour off the silver solution and flood the slide with formalin solution for 1 minute.

7. Examine under microscope, if it needs more repeat steps 5 and 6.

8. Rinse in distilled water.

9. Sodium thiosulphate 5 minutes.

10. Dehydrate and clear through 95% ethanol, 100% ethanol then Histoclear and mount. Axons and dendrites are stained black, other structures are stained light yellow-brown.

Immunohistochemistry

I: Anti-protein gene protein 9.5 (PGP 9.5)

Slides were prepared and divided into three groups: group I had antigen retrieval using 10% formic acid; group II did not have antigen retrieval; and group III was a negative control (no primary antibodies).

Steps:

1: antigen retrieval:

Group I: formic acid 10% was applied on one slide for 10 minutes.

2: 20 ml PBS + 0.1 ml (0.5%) Triton and mixed well then added to all groups. This was repeated three times and each time for five minutes. Then wash up gently with PBS.

3. Circulate around the tissue section as close as possible by using the hydrophobic pen. This step is critical because the tissue section might become dry and in order to prevent this PBS should be applied while waiting for the hydrophobic circle to dry.

4. Prepare antibodies diluent: 10 ml PBS + 100 mg albumin bovine (mix well) then add 10 µl tween 20 (mix well). The antibodies diluent needs to be fresh or no more than a few days old and kept in the refrigerator.

4: Add 10 µl primary antibodies (anti-protein gene protein 9.5: PGP 9.5) to 1000 µl antibodies diluent (NB the antibodies were added to the diluent not vice versa) and the result concentration is 1:100.

7: The primary antibodies (1:100) were put on the slides of group I and II while group III has the diluent only (negative control). All tissue sections were confirmed to be completely covered with the solution. Then they were incubated in a humid box in the refrigerator for two days.

8: Rinse slides gently with PBS 3 X 5 min each slide.

9: Apply the secondary antibody (Chemicon AQ132P) goat anti-rabbit HRP conjugate diluted 1:200 in dilution buffer for 5 hours at room temperature.

10. Rinse gently with PBS 3 X 5 min each slide.

11: Apply DAB solution: (0.05% diaminobenzidine tetrahydrochloride plus 0.03% hydrogen peroxide in PBS). To make this: add 5mg DAB plus 10ul 30% H_2O_2 in 10ml PBS. Then watch reaction: it takes 2 - 5 minutes until the background colour start to appear.

12. Wash several times with PBS and rinse briefly in water.

13. Dehydrate, clear and coverslip as usual.

II: Anti-calcitonin gene-related peptide (CGPR):

Slides were prepared and divided into three groups: group I had antigen retrieval using 10% formic acid; group II did not have antigen retrieval; and group III was a negative control (no primary antibodies). Positive control sections of skin and of axillary artery were processed in parallel as a quality control measure.

Steps:

1: antigen retrieval:

Group I: formic acid 10% was applied on one slide for 10 minutes.

2: 20 ml PBS + 0.1 ml (0.5%) Triton and mix well then added to all groups. It was repeated three times and each time remains for five minutes. Then wash up gently with PBS.

3. Circulate around the tissue section as close as possible by using the hydrophobic pen. This step is critical because the tissue section might become dry and in order to prevent this PBS should be applied while waiting for the hydrophobic circle to dry.

4. Prepare antibodies diluent: 10 ml PBS + 100 mg albumin bovine (mix well) then + 10 µl tween 20 (mix well). The antibodies diluent needs to be fresh or few days old and kept in the refrigerator.

4: Add 10 microliter primary antibodies (**Anti-calcitonin gene-related peptide: CGPR)** to 1000 µl antibodies diluent (Note the antibodies were added to the diluent not vice versa) and the result concentration is 1:100.

7: The primary antibodies (1:100) were put on the slides of groups I, I and IV (positive control) while group III has the diluent only (negative control). All tissue sections were confirmed to be completely covered with the solution. Then they were incubated in a humid box in the refrigerator for two days.

8: Rinse slides gently with PBS 3 X 5 min each slide.

9: Apply the secondary antibody (Chemicon AQ132P) goat anti-rabbit HRP conjugate diluted 1:200 in dilution buffer for 5 hours at room temperature.

10. Rinse gently with PBS 3 X 5 min each slide.

11: Apply DAB solution: (0.05% diaminobenzidine tetrahydrochloride plus 0.03% hydrogen peroxide in PBS). To make this: add 5mg DAB plus 10ul 30% H_2O_2 in 10ml

PBS. Then watch reaction: it takes 2 - 5 minutes until the background colour start to appear.

12. Wash several times with PBS and rinse briefly in water.

13. Dehydrate, clear and coverslip as usual.